Risø annual report 2000

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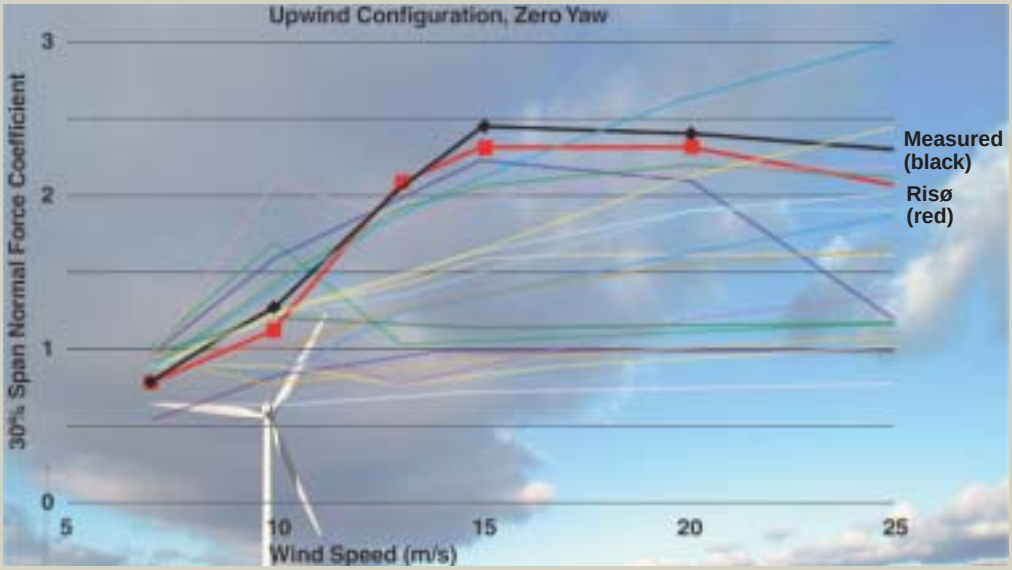
Risø software is best in wind test



Risø best in test: Risø scientists predicted, with a great deal of accuracy, NREL's (National Renewable Energy Laboratory) measurements of aerodynamic conditions around rotating wind turbine blades. Risø was invited to participate in a blind test along with institutions from the USA, Europe and Japan, using their own mathematical models to predict the measurements. Twenty participants took part in this blind test and it emerged that Risø's predictions largely coincided with NREL's actual measurements.

In December 2000, the world's leading wind turbine researchers saw at first hand just how accurately Risø scientists can predict the aerodynamic conditions around wind turbine blades.

The Danish National Renewable Energy Laboratory (NREL) used the world's largest wind tunnel, operated by NASA Ames at Moffet Field, California, to test an experimental turbine 10 metres in diameter. The tunnel is normally used for fixed-wing aircraft and helicopters.

20 institutions from the USA, Europe and Japan were invited to take part in a blind comparison, using their own computer models to predict the results of the wind tunnel tests. Risø's predictions were the most accurate, matching the test results closely.

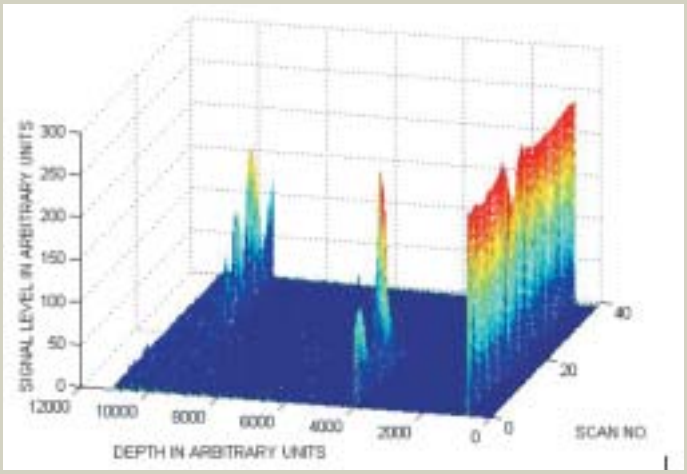
For more than ten years, scientists at Risø and The Danish Technical University (DTU) have worked on a simulation project known as the 'virtual wind tunnel'. The NREL tests indicated their belief that it is possible to simulate wind turbine aerodynamics very accurately. The Risø models are immensely valuable in research and the design of turbine blades.

Plastic muscles for gentle robots

Robot muscles are so-called actuators made of plastic, which can convert an electrical signal into a mechanical movement, delivering propelling force to a motile system with the same suppleness with which muscles move the body.

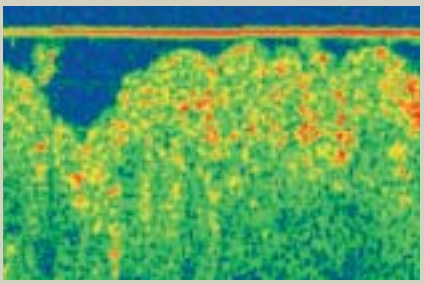
BOYE KOCH

New 3D images give early warning of diseases



In 2000 Risø's contribution yielded a theoretical breakthrough in the physics underlying OCT. These results have made it possible to obtain even more information from OCT images.

Optical coherence tomography (OCT) helps medical doctors diagnose the early stages of skin diseases, including cancer, by distinguishing details up to twenty times more accurately than the human eye. A breakthrough by Risø scientists studying the physics underlying OCT systems allows even more information to be extracted from each image. (Below) A 0.5 mm by 2 mm image of the skin on the lower left forearm of a healthy volunteer. (Left) The novel true reflection algorithm applied to measurements on a tissue-like phantom: the three signals should have approximately equal magnitude as demonstrated.



A new imaging technique being developed at Risø will help medical doctors reveal diseases of the retina, birthmark cancer and vascular disorders in their early stages. Optical coherence tomography (OCT) distinguishes skin details up to twenty times more accurately than the human eye, and can also be used to screen for diseases by matching images from patients against images stored in a library.

Risø is working on OCT in collaboration with the Technical University of Denmark, the University of Copenhagen and Herlev Hospital, in a project supported by the Center for Biomedical Optics and New Laser Systems (BIOP) and the Danish Technical Research Council.

OCT works rather like an echo sounder, shining a narrow beam of light into the skin and measuring the time it takes to be reflected back again. Computer processing then yields a two-dimensional image of a thin slice of the skin. To build up a complete three-dimensional picture of the area of interest, the light beam is moved in small steps and the imaging is repeated slice by slice.

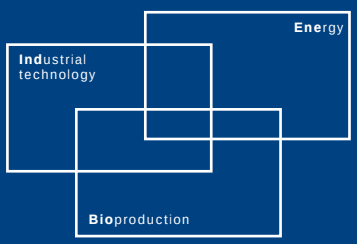
Plastic actuators which mimic the behaviour of living muscles could allow the development of robots to handle delicate objects with a gentleness unmatched by conventional motor-driven robots.

Since 1998, Risø has been working on plastic actuators with Danfoss A/S and The Technical University of Denmark (DTU), under the THOR (Technology by Highly Oriented Research) programme run by the Danish Research Agency.

The project is developing two types of plastic actuator, both of which turn electrical energy directly into linear motion. The first, known as dielectric actuators, are based on rubber materials with special electrical properties. During 2000, the researchers met the objective they had set themselves three years ago by developing a dielectric actuator that can lift 100 times its own weight in less than a second. The drawback of this actuator is that it needs an operating voltage of several thousand volts.

The second type of actuator generates movement from the expansion that occurs when current flows through an electrically conductive polymer. These actuators are slower and weaker than dielectric actuators, but they can operate from an ordinary 1.5 volt battery.

During the coming year, the researchers will develop a demonstration of the possible uses for a soft and supple polymer-based actuator.



2000: a watershed year

2000 turned out to be a watershed for Risø – something the management and Board of Governors could not have predicted at the start of the year. 2001 looks set to be no less significant.

The dominant event during 2000 was the decision to close the DR3 research nuclear reactor. This forced Risø to make 25 employees redundant, and initially threatened to end some highly successful research that has brought Risø world renown for more than four decades.

However, we have made an agreement with the Paul Scherrer Institut in Switzerland to move our three best instruments there. This will allow us to continue some of our neutron-based materials research, albeit in a new role as users of a facility abroad. We plan to transfer responsibility for decommissioning our nuclear facilities to Danish Decommissioning (DD). 70 Risø employees will move to this new organisation, where their technical expertise will be valuable not only in decommissioning existing nuclear plant but also in preparing for the decision on a permanent repository for all of Denmark's radioactive waste.

BOYE KOCH

Research produced much important work in 2000. This Annual Report presents a selection of our research results. More information is available in the printed and electronic versions of the individual research departments' annual progress reports.

Risø's commercial income in 2000 was significantly greater than budgeted. This has partially offset the loss of income from silicon irradiation as a consequence of the closure of DR3, as well as the fact that the reactor was at a standstill for most of 2000 during the investigations that led to its closure.

The new Risø

The closure of DR3 meant saying farewell to a significant element in Risø's identity, but we have already forged a new identity. During 1999, in recognition of the fact that the reactor had a limited lifetime, we began to formulate a strategy for a new Risø without nuclear facilities.

The new strategy focuses on energy, industrial technology and bioproduction. It is based on Risø's unique combination of competences in areas where – along with a number of our sponsors, partners and customers – we have identified significant societal needs and opportunities.

Risø's new strategy was approved by the Board of Governors in November 2000 and launched just before the New Year. The strategy will form the basis of negotiations for a new four-year contract with the Ministry of Research and Information Technology when our present contract expires in 2002.

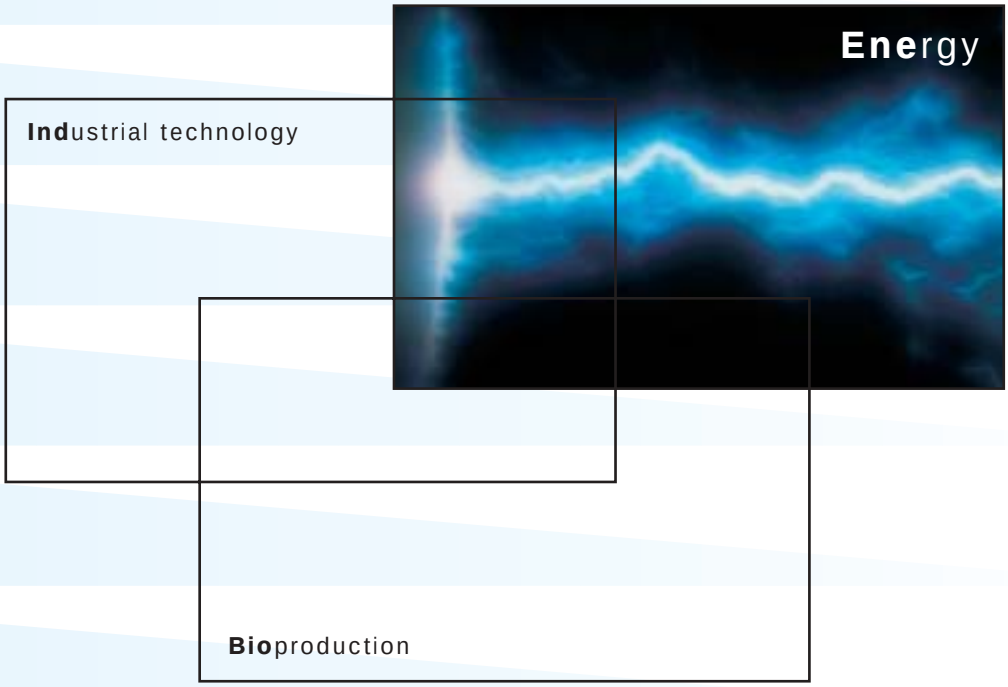
The new strategy serves as a beacon for the transformation process Risø is undergoing in 2001. This Annual Report shows that we produce a healthy return on the research funds invested in us, and it is our ambition for this return to grow over the next few years.

2000 saw the implementation of Risø's first employee satisfaction survey. The results revealed a reasonable level of satisfaction with jobs and with the immediate working environment, but also the need for better collaboration between employees and managers. One follow-up measure has been a review of the concept of staff development interviews. Risø's greatest strength is its highly-qualified and strongly motivated staff. Every manager at Risø will therefore be giving high priority to developing the competences of existing employees and recruiting new talent.

Risø's competent and committed staff are key to our good results. During 2000, employees also put their full energy into preparing Risø's new strategy. We thank them for that.

Jørgen M. Clausen
Chairman of the Board of Governors

Jørgen Kjems
Managing Director



Population growth and rising prosperity are closely linked to increasing energy consumption, increasing emissions of greenhouse gases and global climate change. As the leading Danish energy research centre, Risø is creating new knowledge to help meet global objectives for reducing the environmental effect of growing energy consumption. Risø is also working to fulfil Danish energy policy objectives and to create new opportunities for industry.

Wind energy

SEAS

Based on measurements, Risø scientists are able to predict wind conditions and the corresponding output of wind energy. Shown here is Middelgrunden in Copenhagen Harbour prior to the construction of the wind farm.

High hopes for offshore wind turbines

Risø gathers data on wind and turbulence at eight 50-metre-high meteorological masts in eastern Denmark. The government chose the locations, six of which are offshore, as suitable sites for wind energy. Measurements are gathered for SEAS energy group with a view to establishing wind farms on the sites and developing wind resource models. Based on the measurements, Risø scientists are able to predict wind conditions and the corresponding output of wind energy, as they did before the Middelgrunden wind farm was built in Copenhagen harbour.

Offshore wind farms could make a substantial contribution to Denmark's energy supply. The Danish government has decreed that by 2030, 50% of Denmark's electricity must derive from wind energy, with three-quarters of this being supplied by offshore wind farms.

Wind energy and the national grid

The Danish government's highly ambitious Energi 21 objectives for expanding wind power will require a better understanding of how to link wind farms and conventional power stations.

At the moment, wind farms always run at their maximum available capacity. If there is an oversupply of electricity at any time, conventional power stations are shut down until supply matches demand. With a big expansion in wind energy, however, large wind farms will need to help in the process of regulating electricity supply.

The relationship between wind farms and the rest of the grid can be studied by adapting tools used to model conventional power stations. Risø is leading a project funded by the Danish Energy Agency to model the 12 MW wind farm at Hagesholm, working with Aalborg University, DanControl Engineering A/S and NVE energy suppliers. Risø's dynamic

MICHAEL FISCHER

Objectives for "Energi 21" which involves the expansion of wind power necessitate an understanding of how wind turbines interact with traditional power stations in the supply of power. Risø is spearheading the EFP "Simulation of a wind power plant" project, for which models are being developed with a view to improving the design and control of large-scale wind farms.

models, which simulate the wind farm's individual turbines under different wind conditions, are now being tested against field measurements.

The models will help engineers design new large wind farms that are more flexible in their generating capacity than those of today. Wind farms that can actively contribute to demand regulation will be better placed to replace conventional power stations.

BOYE KOCH

Each year, as part of a framework agreement with the Danish Energy Agency on the accreditation and testing of wind turbines, Risø enters into a contract to conduct activities to promote quality, performance and reliability of wind power plants.

Setting standards for wind power

As the Danish knowledge centre for wind power technology, Risø works with industry, insurance companies, accreditation bodies and user groups to improve the quality, performance and reliability of wind power plants. The work is carried out under a rolling annual contract from the Danish Energy Agency.

Risø's position in helping to set both Danish and international standards for wind generators should in future make it easier for Danish manufacturers to get type approval for their products abroad. The plan is to ensure that designs satisfying the Danish approval scheme also meet international standards.

Recent developments in turbine design have led to a re-examination of the original accreditation system. 2000 saw a new technical basis for the approval of wind turbines in Denmark, a recommendation on generators and an interpretation document relating to power curve measurements. New test methods are under development, as are preparations for new recommendations on the design of gearboxes, rotor blades and offshore turbines.

Risø has been working on ways to measure the quality of electricity produced by wind turbines, especially variable-speed turbines. Other work includes the layout of the new test site at Høvsøre, and planning of the measurement programmes to be carried out there.

The website at www.vindmoellegodkendelse.dk has been expanded to answer most questions relating to the Danish approval scheme for wind turbines.

NORDFOTO

Traditional textile plants such as hemp could ensure the development of large-scale wind turbines. Wind turbine blades being of such large proportions are tending to render traditional construction materials inadequate. Risø is therefore taking a new line, using nature's own fibres instead of traditional fibreglass material.

BOYE KOCH

A pre-pilot plant is being built at Risø in collaboration with Haldor Topsøe A/S. The purpose of the pre-pilot plant is to develop industrial production of fuel cells by optimising all processes and adapting them for full-scale production. Pictured at the top is research technician Kjeld Sandsted, working on the production of an experimental SOFC unit consisting of three serial-linked Rolls-Royce type cells. Below an SEM microscope image of the surface of spheres of crystallized glass can be seen, which has being investigated as a possible sealant for the cells.

More and larger turbine blades on test

During 2000, Risø's wind turbine blade testing centre at Sparkær experienced a tremendous growth in demand. The length of the blades under test also increased, to a maximum of 40 m, and this required investment in new handling equipment.

The hall at Sparkær was built for blades up to 42 m long, so the next generation of longer blades will require enlargement of the hall. These new turbines, which have capacities of more than 2000 kW, are intended for use offshore, where they will be subject to extreme stresses. The Sparkær centre was accredited by Danish Accreditation Scheme (DANAK) in 2000 to carry out static loading and fatigue testing of wind turbine blades.

Plant fibres for lighter wind turbine blades

The blades of the latest wind turbines are so large that they are reaching the limits of conventional construction materials such as glass fibre composites. Risø is therefore taking a new line, using nature's own fibres instead.

The main advantage of plant fibres is that they are lighter than glass or carbon fibres. Like synthetic fibres, they can be encased in a polymer matrix to form composite materials that are light yet strong.

Risø's research shows that the most promising fibres come from flax and hemp, traditional textile plants with relatively long fibres. Plant scientists at Risø are working to characterise the fibres and modify them both chemically and biologically for best performance.

The next step is to pack the fibres and immerse them in resin. Current research focuses on choosing more uniform fibres and aligning them in such a way as to minimise the volume of air in the composite, because too much air weakens the material. The researchers believe that the best matrix material may be a polyester resin. Polyester can be processed at lower temperatures than other resins used for composites, and this avoids the risk of damaging the plant fibres.

Risø's materials researchers are testing the properties of the finished composites and developing full-scale production techniques.

Fuel cell technology

Fuel cells approach mass production

Risø and Haldor Topsøe A/S are building a pre-pilot-scale production plant for solid oxide fuel cells (SOFCs). Due to be ready at the end of 2001, the plant at Risø will form the centre of a three-year project to develop a way to mass-produce SOFCs. Engineers will use the new plant to optimise the manufacturing process and prepare for full-scale production. They aim to balance the quality and price of the fuel cells, maximise cell durability and

lifetime, minimise internal resistance and establish a non-destructive way to characterise the cells.

Fuel cells convert chemical energy into electricity – efficiently, silently and without pollution. One of the front runners in the fuel cell race is the SOFC that Risø has been developing since 1989. The Risø design has unusually high mechanical strength and very low internal resistance, and in contrast to many other fuel cell designs it runs at a temperature below 850°C.

The comparatively low operating temperature means that many parts of the fuel cell can be made from metal instead of ceramic, an important factor in making fuel cells cost-competitive with other methods of producing electricity. We believe Risø's fuel cells could be mass-produced at a price significantly below the EU objective for 2005 of DKK 3,500 per kW.

Superconductor technology

A first for superconductors in the grid

Denmark has become the first country in the world to use superconducting cable in its electricity distribution network. The demonstration project, a 30 m stretch of three-phase high-voltage superconducting cable at Amager Koblingsstation, was commissioned in spring 2001. Risø is helping to develop the superconductor technology, which could in future cut power losses from the grid by more than 40 per cent.

Inside the cable are flat tapes made by Nordic Superconductor Technologies (NST) from silver and superconducting ceramic powder. When cooled to –196°C using liquid nitrogen, the tapes conduct electricity with only very small losses. Because the cooling uses energy, superconductors will show their biggest advantages in cables that carry very high currents, such as those that form the backbone of the national grid.

Risø scientists are working to improve the performance of the superconducting tapes, notably by studying the alignment of the ceramic crystals and how the grain boundaries change when the material is heated during manufacture. They are using X-rays at the DESY synchrotron radiation facility in Hamburg to study crystal alignment, because the superconductors are known to perform best when the grains lie lengthwise and side-by-side, like oat flakes. Magnetic fields also have important effects on the performance of ceramic superconductors, and Risø scientists are studying this.

The participants in the Danish superconductivity project range from basic researchers and supporting agencies to end-users: NKT Research, The Technical University of Denmark (DTU), Risø, NST, the Danish Energy Agency, Elkraft, Eltra, DEFU and NKT Cables.

Record low temperature heralds high-temperature superconductors

Scientists from Risø, Copenhagen University and the Low Temperature Laboratory in Helsinki have cooled a sample of rhodium metal to the lowest temperature ever recorded – just one ten-billionth of a degree Celsius above absolute zero (–273.15°C). The experiment may in future help in the design of superconductors that work at room temperature.

At the moment, even the best 'high-temperature' superconductors lose their superconducting properties at temperatures above –100°C. By learning more about the fundamental mechanisms behind superconductivity, researchers hope to be able to design a material that is superconducting at room temperature.

An important part of this work is the study of the relationship between magnetism and superconductivity. The low-tem-

BOYE KOCH

The participants in the Danish superconductivity project range from basic research interests to end users: NKT Research, DTU, Risø, NST, Elkraft, Eltra, DEFU and NKT Cables. Pictured here is Juan Farré, managing director of NST, with reels of BiSCCO superconducting tapes.

MICHAEL FISCHER

In a thulium-nickel-borocarbide crystal, the magnetic structure is different from that of iron; thus, superconductivity may well exist, even though the material has a magnetic structure. This gives unique possibilities for investigating the interaction between the two phenomena experimentally.

perature experiment confirmed that superconductivity is even affected by the tiny magnetic fields generated by the atomic nuclei of the superconducting material itself.

Power plant technology

Coal-fired power stations innocent in the particles war

Research at Risø has confirmed that Danish coal-burning power stations are not a significant source of fine particles in ambient air. This result is important because forthcoming European Union legislation will limit the allowable concentration of fine particles in outdoor air.

The Risø study, in collaboration with The Technical University of Denmark (DTU) and dust control equipment manufacturer FLS miljø A/S, looked at how fine particles are created in the furnaces of a coal-fired power plant and transported through to the chimney stack.

Risø scientists used low-pressure impactors to collect size-fractionated samples of particles. The chemical composition of the particles was then examined by techniques including neutron activation analysis, a sensitive method using neutrons from the now-closed DR3 reactor.

FLS miljø A/S contributed its expertise as a supplier of electrostatic precipitators (ESPs), which are used to clean flue gas in coal-fired power plants. Data collected during the project can be used to check mathematical models of ESPs and may lead to design improvements.

Faster and better response to nuclear accidents

New work carried out under the Nordic Nuclear Safety Research (NKS) programme will produce faster and better responses to a nuclear accident, especially when dealing with contaminated agricultural land.

After a nuclear accident, fallout over crops and livestock is a big concern. If appropriate action is not taken, contaminated foodstuffs are likely to contribute significantly to the radiation doses people receive.

Unfortunately, agricultural countermeasures are often irreversible and may be mutually conflicting. For instance, is it better to plough the contaminated area, thus rapidly covering up the radioactive fallout, or to go down the slow and difficult route of scraping up the topsoil and disposing of it elsewhere?

Within the NKS research programme, a new car-mounted monitoring system using advanced gamma-ray detectors and satellite navigation equipment will produce high-quality fallout maps of contaminated areas in a matter of minutes or hours. Rapid mapping will allow authorities to take more effective radiation countermeasures.

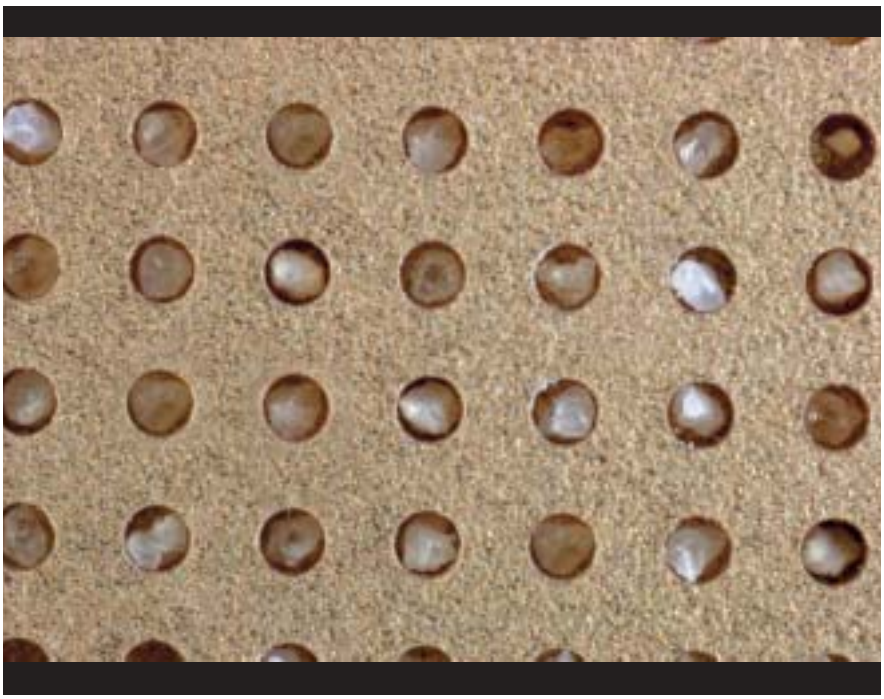
Also within the programme, Risø is developing methods for choosing the most appropriate agricultural countermeasures. Working with agricultural organizations and authorities, Risø scientists are developing computer-based decision support tools that use cost-benefit analysis to compare different countermeasures and set priorities for action.

A new way to measure old radiation doses

A technique used successfully at Risø to date archaeological finds and geological samples is being adapted to measure the doses of radiation to which people have been exposed, for instance after nuclear accidents.

Optically stimulated luminescence (OSL) is a physical phenomenon in which materials such as clay and rock that have been subjected to radiation emit a faint glow when exposed to light of certain wavelengths. The greater the radiation

BOYE KOCH

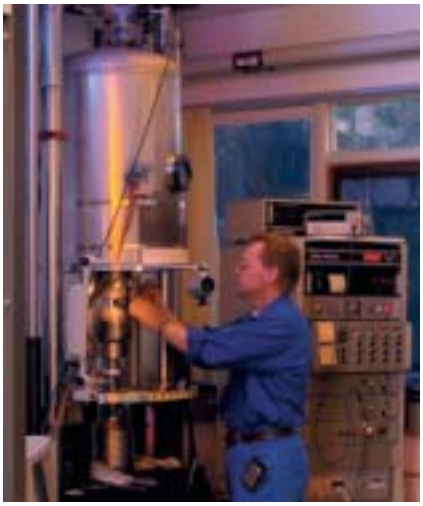


The new single-grain method can be used to select the mineral grains in cement, for example, which can give the correct answer as to how much radiation the material, and consequently the people affected by it in the building, have received after an accident involving radioactivity. The individual grains of quartz are placed in small depressions. OSL signals are stimulated from each individual grain using a focused laser beam controlled in such a way as to selectively impinge on each depression.

JØRN ROED

Masany, Belarus, is one of the places where the soil is polluted with radioactivity following the Chernobyl accident. Research scientists from Risø have developed a method of burying the polluted layer of soil down under the root zone. The method is known as "triple digging", and it means that the soil can be cultivated normally again.

BOYE KOCH



Research technician Benny F. Olsen mounts a sample in a tensile testing machine used for testing materials for the fusion reactors of the future.

dose absorbed, the stronger the glow.

Conditions such as exposure to sunlight or high temperatures can reset this natural radiation counter. When natural clay is used to make a pot, for instance, the high temperature of the firing process wipes out the effect of the radiation the clay has absorbed up to this time. Subsequently, natural background radiation causes the OSL effect to build up again over time.

OSL can be used to measure artifical radiation doses too, but until now it has only been available for bulk materials. Because accurate dose measurement depends on knowing that the whole sample has been reset to what scientists call the zero point, OSL dosimetry works for fired materials such as pottery but not for concrete, which contains material that has not been reset.

Now Risø scientists have found a way to measure the luminescence of a single grain of material. By breaking down a sample of concrete and analysing only those grains that have been properly reset to the zero point by heat or sunlight, they should be able to get accurate OSL dosimetry results from concrete and other materials that were formerly unsuitable for this technique.

A foreign post-doc and a Danish Ph.D. student will spend the next three years developing reliable and accurate OSL dosimetry techniques for concrete and similar materials.

Public information to people affected by Chernobyl

A scientist from Risø is playing an important part in a public information campaign for people affected by the nuclear accident at Chernobyl. The scope of the work ranges from better information for doctors and nurses to advice on how to deal with contaminated mushrooms.

Through a long series of research projects, especially in the years after Chernobyl, Risø has developed many techniques for removing radioactive contaminants from people, houses and food. As a result, the Dutch company SPAN Consultants asked Risø to lead the research team for this ambitious public information project.

The Risø scientist has overall responsibility for 15 subprojects: five in the Ukraine, five in Belarus and five in Russia. He has personally chosen most of the scientists working on the project, and now spends much of his time supervising activities in the contaminated areas.

One of the subprojects is on edible fungi, which are an important food source for many people in the contaminated areas. Some species of fungi are badly contaminated with radionuclides, while others are much less affected, so local people can cut their radiation intake by choosing carefully. The project also explains various highly-effective methods of reducing the radionuclide content of fungi.

Another subproject is training local doctors and nurses in the facts about radiation and its effects. This is important because experience has shown that poorly-trained doctors and nurses spread many prejudices and myths about radiation.

Stronger walls for fusion reactors

If nuclear fusion is ever to become a practical source of power, scientists will

have to develop construction materials that can withstand the intense neutron radiation inside a fusion reactor. Risø is investigating suitable materials as its contribution to the International Thermonuclear Experimental Reactor (ITER) project.

Risø's part in ITER, which links the EU, Japan, Russia and the USA, stems from its membership of the pan-European fusion programme. The ITER reactor will use temperatures of up to 100 million degrees Celsius to fuse deuterium and tritium nuclei, with the release of energy in the form of neutrons.

Using both experiments and theoretical studies, Risø has built up a basic knowledge of how neutron radiation affects the microstructure of different materials, and hence their bulk physical and mechanical properties. During 2000 Risø scientists studied copper and titanium alloys, both of which may be used for the walls of fusion reactors.

The objective is to develop a reactor wall capable of withstanding neutron irradiation for at least 20 years, a realistic lifetime for an economically viable reactor.

Cutting-edge simulation of plasma turbulence

During 2000, a comparison of computer simulation codes developed at Risø with those of the prestigious Max-Planck-Institut für Plasmaphysik (IPP) in Germany showed that Risø scientists have an excellent understanding of plasma turbulence in fusion reactors. The Risø codes proved to be fully up to the standards of their IPP counterparts, and were in some respects better. As a result, IPP and Risø have since been collaborating closely.

Making measurements on anything as hot as a fusion reactor is a complex matter, so physicists also rely on computer simulations to study the plasma inside the reactor. Turbulence in fluids such as air and water is hard to model, but turbulence in plasma is even more complex because it is affected by electric and magnetic fields. Plasma simulations therefore need very specialised programs running on supercomputers.

Climate and Kyoto

Risø trains African climate negotiators

Risø has been helping to ensure that Africa gets a fair deal on environmental issues. This work has been carried out through the UNEP Centre, which was established in 1990 as a joint venture between UNEP (the United Nations Environment Programme), Risø and Danish International Development Agency (Danida).

One of the Centre's achievements during 2000 was the completion of a project to make African negotiators better equipped to take part in international climate change negotiations. The project, which was funded by Danida, took the form of a series of regional meetings and technical consultations. Risø has received positive feedback on its work, especially at the Hague climate conference in November 2000, where African negotiators played an increased role.

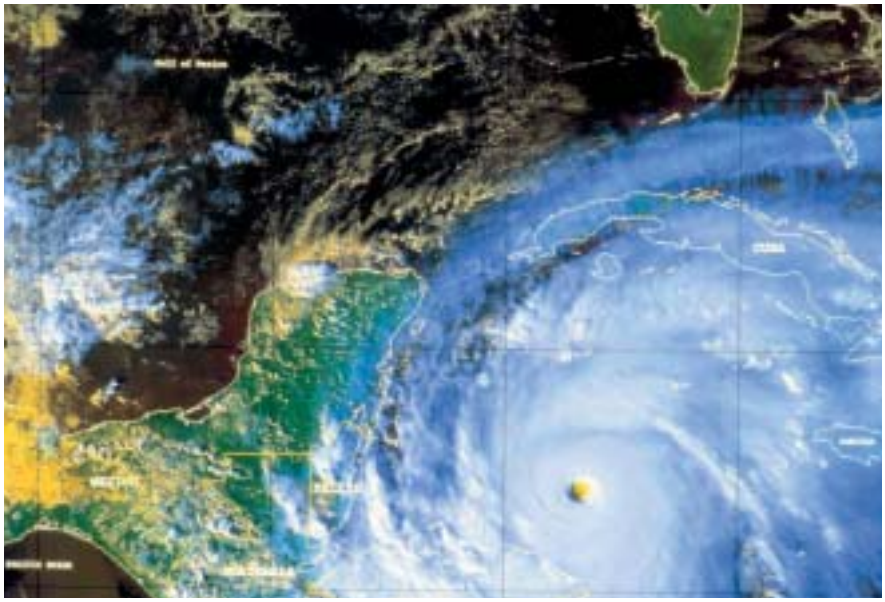
The Centre has also completed studies of how three African countries can win projects under the Clean Development Mechanism (CDM). Under the CDM, industrialised countries can invest in sustainable development projects in specific developing countries. In return, they can offset part of the emissions reductions achieved by these projects against their own national reduction targets.

Four Risø scientists were elected to the Intergovernmental Panel on Climate Change (IPCC). They contributed to two IPCC Special Reports, on emissions scenarios and North-South technology transfer respectively, and to the general Third Assessment Report (TAR). TAR, which represents the latest combined scientific assessment of all climate problems, will be published during 2001.

NORDFOTO

Climate scientists are becoming increasingly more certain that we are faced with global climate changes. The effects are e.g. that ocean levels are rising and we can expect more extreme weather such as flooding and storms. A new focusing framework for Risø's energy research is based on analysis of future post-Kyoto climate targets and the possible new requirements this present for future energy supplies when it comes to emission reductions.

The "Third Assessment Report" is the latest report by the UN climate panel IPCC (Intergovernmental Panel on Climate Change), and the most direct with respect to the unavoidable climate changes that will lead, for example, to more situations involving extreme weather such as hurricanes. Three of Risø's research scientists were elected as members of IPCC and contributed to the completion of two "Special Reports" as well as the general IPCC "Third Assesment Report".



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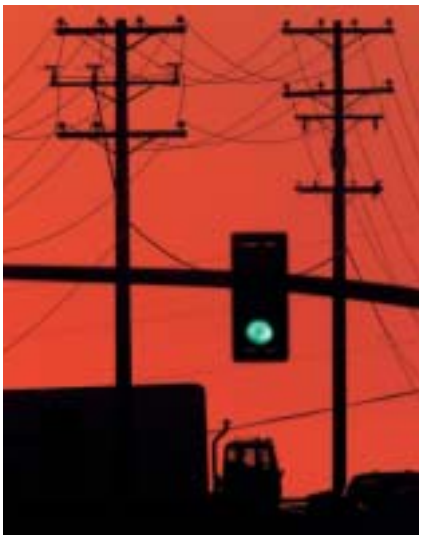


The EU Member States have agreed that one of the methods of promoting more sustainable electricity production is by issuing the various providers of electric power with certificates in accordance with how the electricity is produced. Risø takes part in EU projects with the aim of describing a model for an international electricity market promoting sustainable sources of energy.

'Green certificates' promote geographical balance in sustainable energy

The European Union (EU) is committed to encouraging the growth of sustainable energy among its member states. One way to achieve this is by certifying each electricity supplier according to its energy sources. By 2010, the plan is for the average EU citizen to get 12.5 per cent of his or her electricity from sustainable sources (excluding large hydroelectric plants, for which the figure is 21.7 per cent).

The proportion of electricity available from sustainable sources, however, varies greatly from country to country. Denmark, for example, aims to get as much as 29 per cent of its electricity from sustainable sources by 2010, whereas in Italy sustainable energy will contribute less than 6 per cent.

To balance this, the EU plans an international electricity trading mechanism that will steer Europe in the direction of sustainable energy. The idea is to let market mechanisms, not individual countries' treasuries, control where sustainable energy is produced. This will help ensure that sustainable energy plants are positioned in the most appropriate locations.

Risø is involved in the REBUS and IntraCert projects under the EU's 5th Framework Programme on research and development. Both these projects aim to describe a model for an international electricity market that will promote sustainable sources of energy.

Risø is also contributing to the "Virkemidler til VE-udbygning" (Ways to Expand Renewable Energy) project under the Energy Research Programme of the Danish Energy Agency. This uses mathematical models to describe the relationship between green certificates and permitted emissions, and predicts how this complex interaction will function.

Helping Denmark comply with international climate agreements

Countries bound by international agreements on climate change need to know what emissions they are producing and how the picture is set to change in the future. Risø is carrying out this task for the Danish government.

By signing and ratifying the Kyoto and ECE (Economic Commission for Europe) protocols, Denmark has pledged to reduce its atmospheric emissions of substances that contribute to climate change. Risø supplies the Danish Ministry of Environment and Energy with statistics on current emissions, projections for the future, financial calculations and ideas for new ways to meet the country's obligations.

The projections are updated each year to reflect changes in the government's

Plant growth and colonisation of plants is measured using a pin, which is lowered through holes in the stand. This is done at a large number of measurement points, which makes it possible to statistically evaluate how the vegetation reacts to climatic changes created artificially using large reflective curtains.

plans for energy, waste, forestry, the aquatic environment and ammonia. As well as greenhouse gases, Risø provides information on oxides of sulphur and nitrogen, which cause acidification.

Risø is also working with other research institutions and the Ministry of Food, Agriculture and Fisheries to calculate how new farming methods will affect emissions. For example, replacing maize crops with elephant grass has several environmental benefits. As well as yielding a fuel that could replace fossil fuels, the elephant grass stores carbon in the soil, reduces emissions of the greenhouse gas nitrous oxide, and cuts carbon dioxide pollution from tractors used for ploughing.

How economic development affects the environment

Government financial budgets commonly include predictions of how changes in taxes and public spending will affect figures such as unemployment and the balance of payments. Risø is helping the Danish government extend this idea to the environmental effects of economic development, such as emissions of greenhouse gases, acidification, eutrophication and the amount of waste.

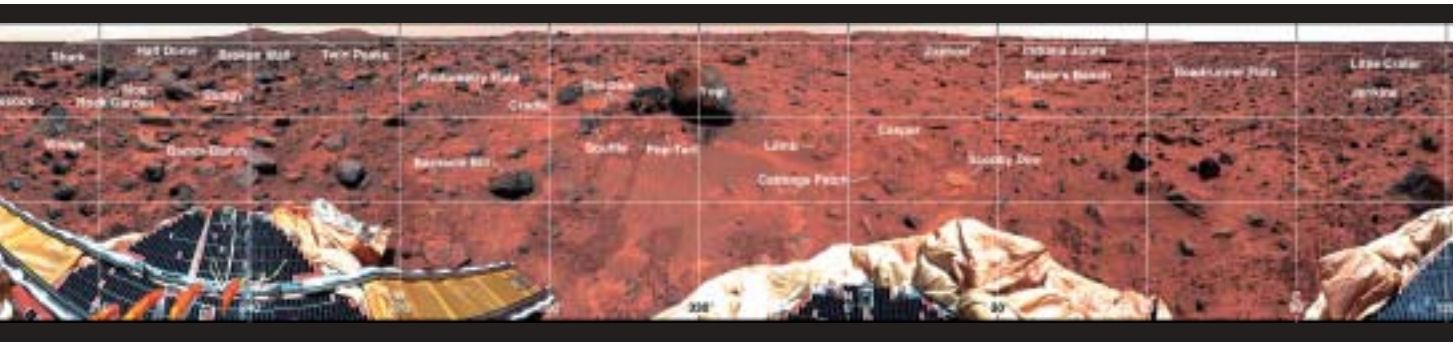
Risø has contributed to a model that describes how energy consumption and energy-related emissions depend on the rest of the economy. The model, called EMMA, is now being used by government economists as a supplement to ADAM, the official Danish budget model.

Through a project under the Strategic Environmental Research Programme, Risø is helping to build a new model, LADA, that will link developments in agriculture with emissions to air and water. Also taking part in the project are the National Environmental Research Institute of Denmark, Statistics Denmark and the Danish Institute of Agriculture and Fisheries Economics.

Such models can be used to create an overall picture of how economic policy and development affect the environment.

Global warming threatens heaths and moors

Global warming could lead to heather being replaced by grass, an experiment involving Risø has shown. If this were to happen, it would change the nature of



NASA

Meteorologists from Risø were part of the science team following Pathfinder on Mars. Analysis of the great quantity of data could result in better climate models.

much of Europe's countryside and cause the loss of many species which live only on heath and moorland.

Risø is one of six partners in an EU project investigating the effect of climate change on semi-natural ecosystems such as heathland. The partners wanted to know what would happen in two cases: first, if the climate simply became warmer, and second, if the pattern of rainfall changes, bringing lengthy dry spells in the summer.

Risø developed a way to answer these questions using field-scale experiments. The tests have been in progress for two years now at Mols Bjerge in Denmark and at similar sites in Wales, the Netherlands and Spain.

So far, the experiments have shown that while drought hinders the growth of grass, a rise in temperature of just 1°C favours grass at the expense of heather. The knowledge of how climate change could affect heath and moorland, an increasingly scarce habitat in Europe, should help politicians take sensible decisions on national and international emissions of carbon dioxide.

European forests help mitigate the greenhouse effect

Figures collected by Risø researchers are helping to show that over the course of a year, Europe's forests absorb more carbon dioxide than they emit, thus helping to reduce the greenhouse effect.

Most European forests appear to be net absorbers of carbon dioxide, but data from 15 measuring stations reveals that the carbon dioxide balance depends strongly on latitude. The Italian forest being studied absorbs much more carbon dioxide than the Danish forest, while some Swedish forests are net emitters of carbon dioxide.

Since 1996, researchers across Europe have been working together on this problem under the EUROFLUX project. Their network of 30 forests extends from Umeå in northern Sweden to Rome in the south. Throughout the year, advanced measuring instruments at the Danish measuring station near Sorø send a continuous stream of data to computers at Risø.

The plants' net exchange of carbon dioxide is measured using a technique called eddy correlation. The concentration of carbon dioxide in the air is measured ten times a second, whilst the vertical air speed is measured simultaneously.

Plants absorb carbon dioxide through photosynthesis and give off carbon dioxide through respiration. The researchers have shown that photosynthesis is largely independent of latitude, but that respiration is greater in northern latitudes. This is probably because respiration depends on humidity, and the summer scarcity of water in southern Europe causes respiration to cease.

The EUROFLUX measurements will continue for several years more. The resulting data will be used, among other things, to develop models to predict how forests will respond to future climate change.

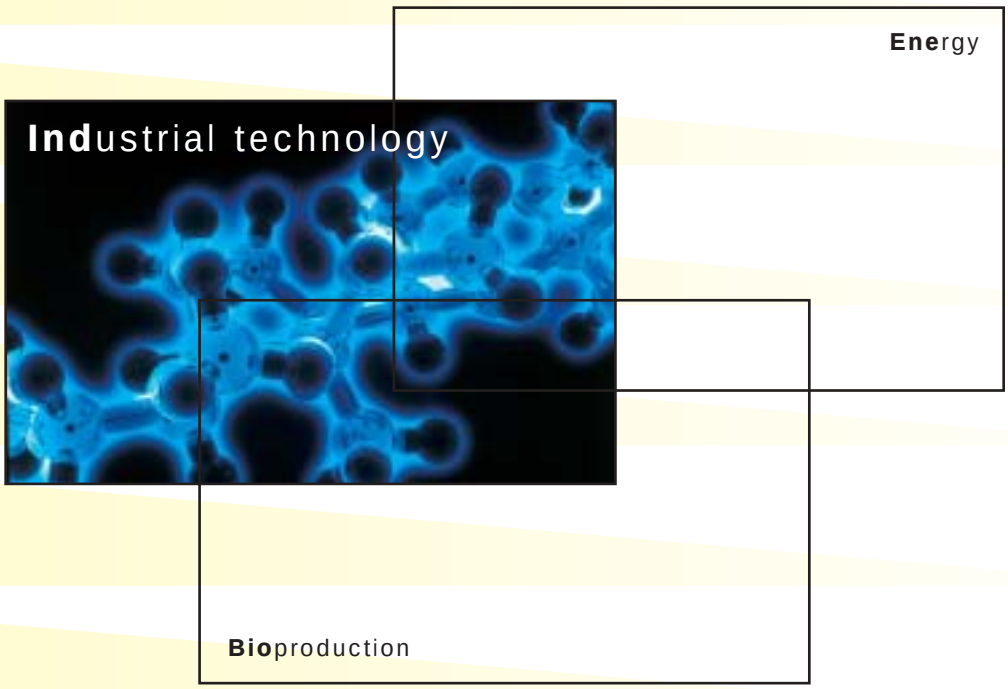
Mars mission improves earthly climate models

Meteorologists from Risø helped NASA design the instrumentation and measurement strategy used by the Pathfinder spacecraft to sample the atmosphere of Mars. After the mission they worked on analysing the data, and they will also be involved in the missions to Mars planned for the years running up to 2007.

It has taken several years to analyse the Pathfinder data, partly because the Mars lander's wind speed measurements were completely wrong. To correct the figures, the researchers had first to recalibrate a copy of the wind sensor in a replica Mars environment. The resulting information is important, however, because it has improved our understanding not just of Mars but of the Earth's atmosphere too.

Climate models are research scientists' most important tools in predicting what will happen when we release large quantities of extra greenhouse gases into the atmosphere. In mathematical terms and on a large scale, climate models describe the entire atmosphere and general trends in the earth's climate.

Apart from the first Mars landings in the 1960s, the Pathfinder mission is the only source of direct measurements from an atmosphere other than Earth's. Comparing the measurements with predictions from models of the Martian atmosphere helps researchers better understand the strengths and weaknesses of their terrestrial climate models.



Risø's efforts in industrial technology aim to help Danish industry grow and develop. The objective is to create new, long-term development possibilities and synergy in materials, optics, sensors and plant biotechnology. Another very important area for the future is inter-disciplinary research on nanotechnology, which deals with structures on the scale of individual atoms and molecules (one nanometre is a millionth of a millimetre).

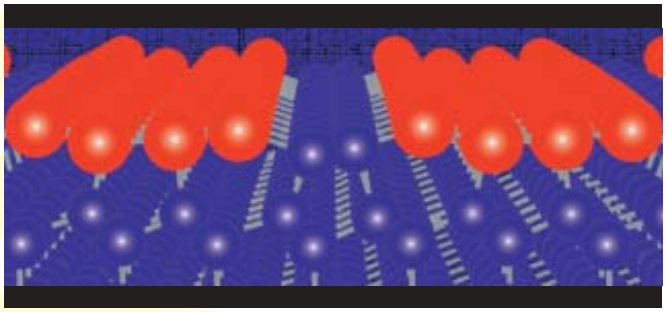
New technology on a nano-scale

Surprising facts about nano-conductors

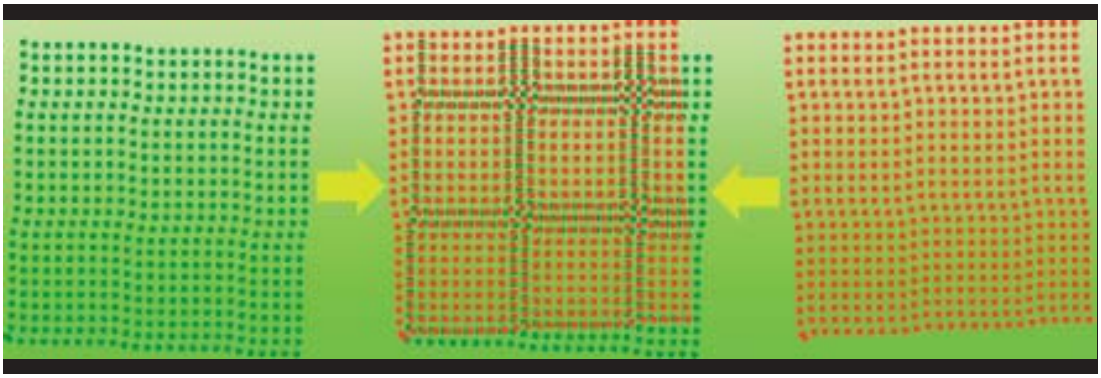
Microchips – digital integrated circuits – are shrinking steadily in size even as they grow in power. Eventually, the individual electronic components that make up each chip will be so small that they will have to be built up directly from individual molecules or atoms. 'Nano-scale' components, even those as simple as pieces of wire, behave very differently from their counterparts in the visible world. At the molecular level, the rules of physics effectively change: quantum effects that can be safely ignored in ordinary circuit design become important in nanotechnology. Not surprisingly, this is a fascinating and fruitful area for research.

Scientists at Risø have been working to create nano-conductors – molecular 'wires' – using the same principles of self-organisation that form beautiful crystals in nature. Indium atoms applied to a silicon surface, for instance, can arrange themselves into long chains separated by rows of silicon atoms.

The researchers have found that a nano-conductor of this type takes on completely different properties when it is cooled to temperatures below -180°C. X-ray scattering studies show that at low temperatures the atoms alter their positions, so that neighbouring indium wires interact with one other.



The trend is towards higher-performance microchips that take up less space. The ultimate objective is to make the electronic components so small that they will have to be constructed directly at the molecular and atomic level. This requires correspondingly tiny conductors. A group of Risø scientists have recently shown that in such a nano-conductor, atomic rearrangements occur which make the conductors interact with each other.



Put two silicon crystals together and turn the two silicon crystal lattices slightly in opposite directions. This gives you a nano-sized ruler, with a variable scale depending on the angle of rotation between the crystals.

Nano-sized rulers for next-generation lasers

Italian scientists have shown that nanometre-sized silicon particles can emit laser light. This discovery could have enormous application in communications technology, which depends heavily on lasers, if we could manufacture silicon particles of the correct size and arrange them in a lattice structure. Researchers at Risø have been working to create suitable lattices.

Two flat crystals of pure silicon can be bonded together in an ultra-clean environment using nothing more than heat and slight pressure. If the lattice structures of the two crystals are aligned, the result is simply a single large crystal.

If the lattices are rotated relative to one another, bonding still takes place. In this case, however, the boundary layer at which the bond occurs shows an interference pattern whose spacing depends on the lattice dimensions and the angle between the crystals. This interference pattern could act as a template for the creation of nano-particles of a specific size, aligned at specific intervals.

To create interference patterns, Risø researchers have been working with two companies: Topsil, which supplies pure silicon crystals, and Mikroelektronik Centret, which provides the clean room and other processing facilities. Using synchrotron X-ray radiation, they have shown that the interference patterns really exist. If the pattern is to be visible on the surface of the crystal, however – as it would have to be as a template – one of the two silicon crystals must be extremely thin. During 2000, the researchers showed that the pattern is visible on the surface when a 0.3 mm crystal bonds with one just 5 nanometres thick.

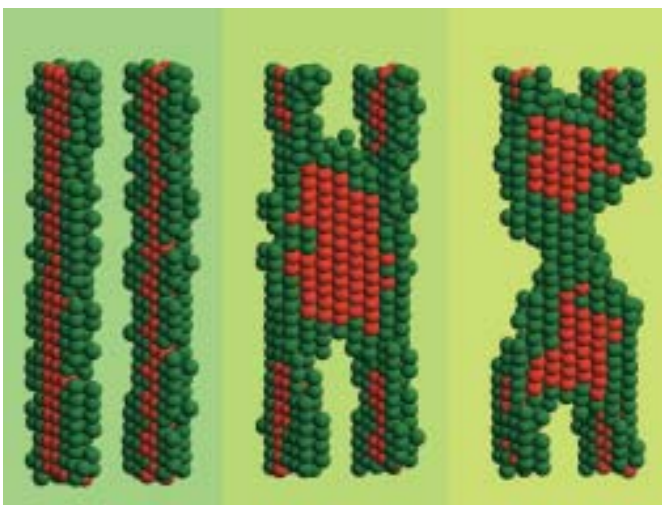
Computer simulations at the atomic level create better materials

New results obtained by Risø scientists will one day contribute to more accurate predictions of the lifetime of machine components, as well as new metals with improved resistance to fatigue.

Recent theoretical knowledge on the frequency of a phenomenon known as cross slip will be applied to the modelling of metal fatigue. This will create a link between atomic-level processes, which occur at the nanometre scale, and existing models which extend down to the micrometre scale.

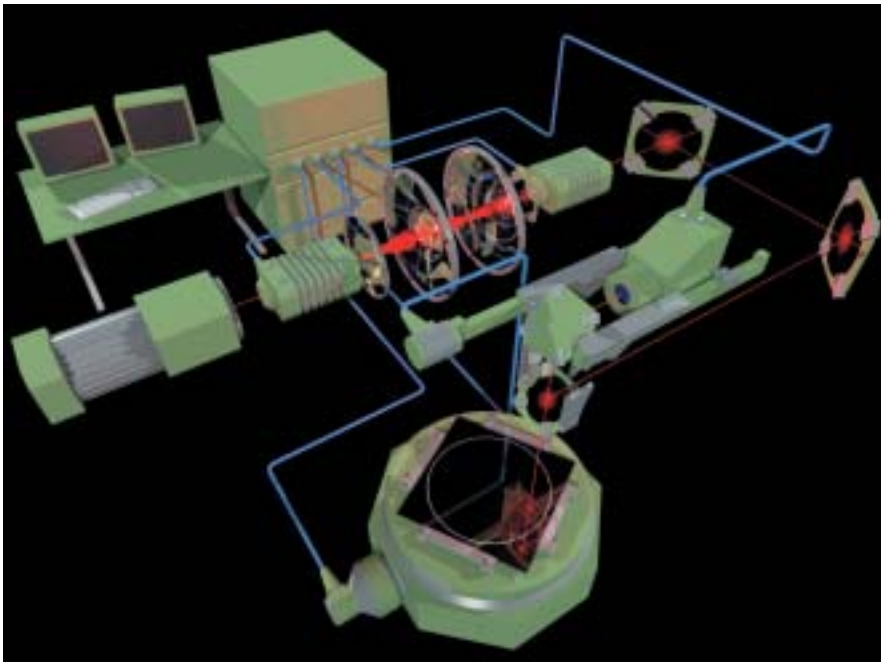
Underlying the new results are comprehensive computer simulations of atomic-level processes in metals undergoing plastic deformation, which occurs when a metal is deformed to such an extent that it cannot recover its original shape.

Plastic deformation happens when a



Computer simulations of metal deformation has led to a theoretical breakthrough that could contribute to more accurate predictions of the lifetime of machine components. The illustration shows three steps in the process, with two so-called screw dislocations colliding during cross-slip, ultimately cancelling each other out (disappearing). Coloured atoms represent irregularities in the atomic structure. Regularly-positioned atoms are not seen.

GRAFIK: SØREN PEO PEDERSEN



This is what a nano-feature typewriter looks like. This nano plotter can type up to 700 separate lines beside each other on the width of a single hair. For the research centre DERA in the UK, holograms are written to simulate three-dimensional computer screens to allow CAD-CAM designers to see their designs in 3D as they work on them.

large number of dislocations – linear irregularities in the atomic structure – move around inside the metal. Some of these dislocations, of the kind known as screw dislocations, can become involved in a process called cross slip. Among other effects, cross slip can cause two screw dislocations to collide and annihilate one another.

Researchers have known for a long time that cross slip is important in metal fatigue and other phenomena. Now scientists from The Technical University of Denmark (DTU) and Risø have joined forces to model cross slip at the atomic level and to find out how often it happens.

The frequency of cross-slip depends on the Arrhenius equation, a mathematical formulation that is very familiar to chemists. The Arrhenius equation has two parts, known respectively as the exponential part and the pre-exponential factor.

After first studying the exponential part, the researchers turned their attention to modelling the pre-exponential factor for a process in which two screw dislocations annihilate one another through cross slip, using a computer model containing around 130,000 atoms. This is the first time the pre-exponential factor has been determined at the atomic level for such a complex process.

Nano-scale typewriter

In a clean room in the Optics and Fluid Dynamics Department at Risø is a 'nano-plotter' – a machine that can draw up to 700 separate lines in the width of a single hair.

Applications of the nano-plotter include producing the optical gratings used to make holograms. One of Risø's customers for this work is the UK Defence Evaluation and Research Agency (DERA), which uses holograms to create three-dimensional displays from flat computer screens. Thanks to the holograms, DERA's CAD-CAM designers can see their drawings in 3-D while they work on them.

The nano-plotter also produces diffraction gratings for optical measuring systems, some of which have been patented. This work is carried out under a project run by the Centre for Miniaturisation of Optical Sensors (MINOS), under the sensor initiative of the Danish Agency for Trade and Industry, and funded by Sensor Technology Centre A/S.

The nano-plotter is also used to produce phase filters for optical tweezers and in the development of artificial muscles, both described elsewhere in this Annual Report.

The nano-plotter looks a little like a record player or a CD writer, in that it has a disk revolving at constant speed and a stationary read/write head. The disk is coated with photoresist or silver film, onto which the head writes with a light beam. A dedicated computer handles the large amounts of data necessary to create the plot. The computer transfers its results to an interface unit which controls the actual writing process, and also reads information back from the disk to ensure that writing takes place at the correct spot on the disk. The nano-plotter can generate very precise and well-defined surface structures, including soft sinusoidal structures.

Live 3-D images from the micro-universe of metals

Before a piece of freshly-smelted metal can become a usable product, it must be processed in many different ways. As the metal is rolled and pressed, heated and cooled, the many billions of tiny grains of which it is composed undergo many changes too. Grains change shape, some grains break down and disappear, and new grains form. The strength and toughness of the finished product depend to a great extent on the structure of these grains.

Using a new device developed at Risø, it is now possible to 'videotape' what

happens to individual grains of metal during processing. The instrument uses powerful X-rays from the ESRF pan-European research centre in Grenoble. Using advanced optics, the X-ray beam is focused inside the metal so as to 'photograph' a slice one micrometre – approximately 10,000 atoms – thick.

The beam is then moved by one micrometre and another snapshot taken. This continues layer by layer until the desired sample thickness has been photographed. Each layer is analysed individually, using advanced image-analysis software developed at Risø to recognise each grain by its unique shape or 'fingerprint'. Finally, the results are combined to produce a 3-D image of the metal grains.

The results can be used to improve the models describing how metals behave during different processing operations, and could even help engineers design completely new materials. The instrument is available for contract use by industry and research organisations.

Polymer materials

Centre for Surface Metrology and Functionality off to a good start

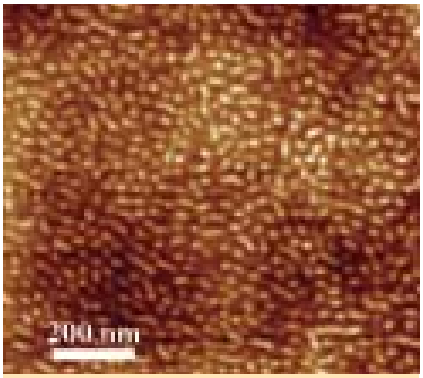
Sticking plaster adhesive is more complex than you might think. Plasters for bedsores, for example, must stay securely in position while the sore heals, but when the dressing needs to be changed they must peel off easily to avoid damaging the delicate new skin. Plasters for stoma bags must be absolutely leak-tight, but do not have to stay in position for so long, and need not be so easy to remove. Other types of plaster require adhesives with still other properties.

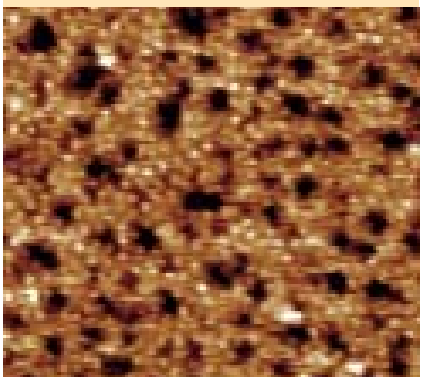
Chemists are able to tailor purpose-designed adhesives from block copolymers – long-chain molecules made up from two or more different types of 'building block'. Each block itself comprises many smaller, identical, repeating units. The different types of block repel one another so that they remain physically separate.

The copolymer behaves as a synthetic rubber made up of two or more different materials, one type of which can be designed to be soft while another type is hard. Adding an oil makes the rubber sticky and creates an adhesive that can be used to coat the whole plaster, even above the actual wound. Finally, moisture-absorbing substances are added to promote healing by keeping the wound moist.

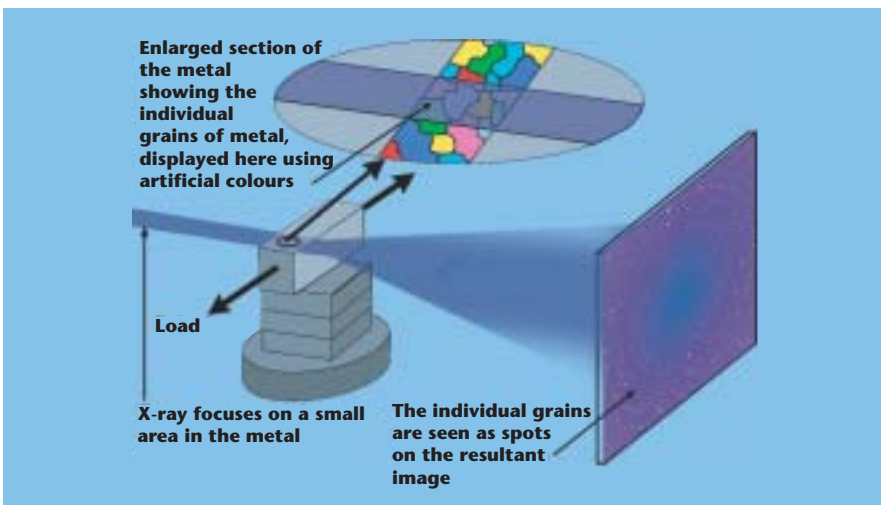
The properties of the adhesive are varied by changing the nature and relative amounts of the different polymer building blocks. Researchers in the new Centre for Surface Metrology and Functionality at Risø are working to understand and control the copolymer structure at the nano-scale. This, they believe, will allow them to fine-tune the properties of the adhesive even more precisely.

This is just one example from a wide range of industrially relevant projects performed at the Centre, which is a colla-



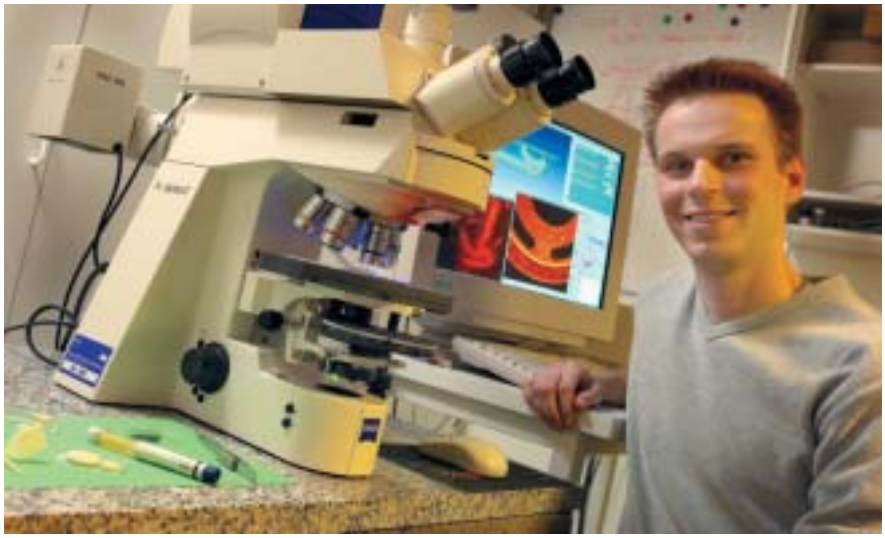


Some types of plasters are made by applying an oil to a rubber base (making the rubber sticky), as well as hydrocolloids (moisture-absorbing substances) that keep the sore moist. Depicted here are Atomic Force Microscopy images of structures in the rubber material before (image with measuring-scale insert) and after applying the additive substances.



Using a new device developed at Risø, it is now possible to "videotape" what happens to the individual grains of a metal during processing. An X-ray beam 'photographs' the individual grains and, using advanced computer programs, it is possible to follow how each grain rotates and fragments during processing.

Senior research scientist Niels Bent Larsen at Risø's new confocal microscope, which is capable of imaging and measuring both the outer surface of specimens and the spatial distribution of components inside the specimen. In front of the microscope a number of examples of specimens examined are shown, obtained from research and collaboration with industry



BOYE KOCH

boration between Risø, the Danish Technological Institute, the Danish Institute of Fundamental Metrology and seven companies both large and small.

Drive and vision at the Danish Polymer Centre

Formed in 1999 as an extension of the collaboration between Risø and The Technical University of Denmark (DTU), the Danish Polymer Centre (www.polymers.dk) grew during 2000 in vision as well as in material terms.

The Polymer Centre has already mapped out an ambitious course that will one day make it one of Europe's leading polymer research centres. In support of this, 2000 saw the start of a large number of new projects: five new Ph.D. projects, one of which is in collaboration with Aarhus University; ten new research projects, some involving foreign postdocs and guest scientists; and a talent project that aims to create a scientific basis for plastic solar cells.

Also new in 2000 was a contract between the Polymer Centre, the FORCE Institute and ten large companies, under the auspices of the Danish Agency for Trade and Industry. The project will deepen our understanding of molecular breakdown, and so lead to more durable plastic products.

Towards the end of the year, the two DTU groups concerned moved into a newly-refurbished laboratory, and the staff based at Risø joined forces to become a single department under the Polymer Centre manager. Risø's Human Resources Department helped set up a 'joint values' project, in which all the Polymer Centre staff members took part in three one-day seminars to create values and visions for the Centre.

How enzymes break down fat

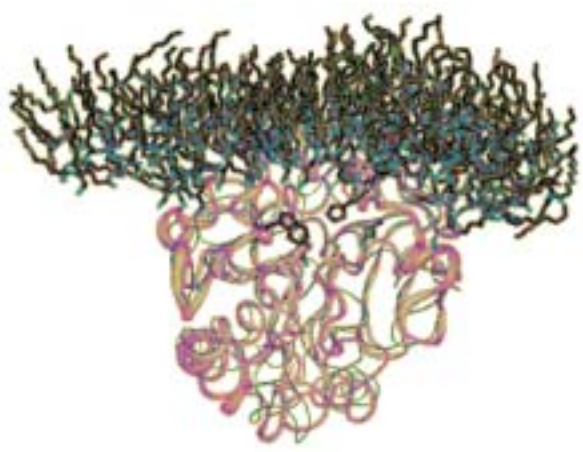
Enzymes known as lipases are added to washing powder because of their power to break down fat molecules into smaller pieces, which then dissolve more easily. But how exactly do lipases work? This has been the subject of a European collaborative project involving ten European universities and research institutions. The Danish participants were Novozymes, the University of Copenhagen, The Technical University of Denmark (DTU) and Risø.

Risø's contribution to the project was to characterise the interaction between lipases and fats at the molecular level using X-ray diffraction. The Risø researchers has studied a model system consisting of a single layer of fat molecules floating on water.

When lipases are added to the water they start to break down the fat molecules immediately, leaving only a short time to study their interaction with intact fat molecules. To give the Risø scientists more time to work, enzyme manufacturer Novozymes has developed inactive lipases that are attracted by the fat layer but do not attack it.

Pure organic materials for medical diagnosis

In 2000, Risø extended its contract with the Dutch-American medical company Mallinckrodt Medical. Mallinckrodt sup-



How do enzymes actually degrade fat molecules? This has been studied at Risø. The computer graphic represents a lipase molecule under a monolayer of fat molecules.

plies radioactively-labelled pharmaceutical products for the diagnosis of disease. Some of these products start life at Risø, where synthesis protocols are developed and the pure organic substances manufactured. Mallinckrodt subsequently adds the radioactive labels.

Risø has so far developed synthesis routes for three substances and has another on the way. As well as providing commercial revenue, this collaborative venture has enabled Risø to develop considerable competence in organic synthesis. The substances have to be manufactured in accordance with the widely-accepted GMP (Good Manufacturing Practice of the Pharmaceutical Industries) regulations. Risø has therefore set up a laboratory that operates to GMP standards.

Optics and sensor technology

Large medical records on small, safe plastic cards

In 2000 a fruitful collaboration between the international company Optilink and Risø resulted in a plastic card that is the size of an ordinary credit card but which can store 10 megabytes of information per square centimetre. The first potential customers for this next-generation 'smart card' will be in the public health sector.

Because the card is small and robust, it gives easy access to information anywhere in the world. It holds much more information than existing smart cards, and it is also more secure – so it is an ideal way to store sensitive information such as personal medical records.

The storage medium consists of a thin film of polyester, in which information is stored as holograms. Lasers used to read and write data to the card can also erase the holograms, allowing the card to be re-used.

The scientists participating in the project expect that within the next couple of years they can increase the storage density from 10 to 30–40 megabytes per square centimetre. Optilink has taken over Risø's patents for the storage medium and is responsible for developing prototypes and commercial systems. Risø is in charge of further developing the storage material itself.

Low-priced lasers for the graphics industry

If paper-based publications are to compete with the Web, they may have to produce very small print runs at low cost. Key to this concept of 'print-on-demand' is computer-to-plate (CTP) technology, which bypasses several steps of the traditional printing process. Risø has developed a technology that promises a breakthrough in printing.

One of the most advanced CTP technologies is known as thermal internal-drum, where a high-power laser beam writes directly on a polymer offset plate. The required high-power precision lasers cost DKK 200,000–300,000 each.

With financial support from the Danish graphics company Purup-Eskofot, Risø has developed a laser that costs only one-fifth as much, yet meets the necessary standards. Key to the cost saving is the use of laser diodes, which are cheap but produce light with low spatial coherence. The new system takes the poor-quality light from the laser diodes and transforms it into narrow, tightly-focused beams.

During the next two years Purup-Eskofot will spend several million Danish kroner on developing the technology.

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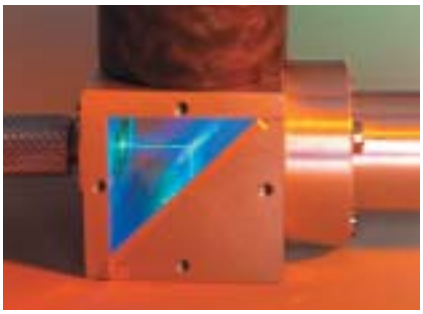


In a joint undertaking with Lund University Hospital, which has a world-renowned radiation treatment centre, Risø is to further develop and test a measuring sensor for monitoring radiation treatment of cancer. Shown here is a section of the equipment. The green stimulation laser beam and the reflected blue OSL signal can been seen here.

BOYE KOCH

Paul Michael Petersen (right) and Sussie Juul Jensen of the Optics and Fluid Dynamics Department show a prototype of their new laser, which produces high-quality laser light from an array of laser diodes. Danish graphics equipment manufacturer Purup-Eskofot is funding the development of the laser that can be used in the printing industry.

POLFOTO

Fibreglass composite springs for a small goods wagon offer reductions in noise, wear and tear. Furthermore, a steel spring weighs 120 kg, whereas the fibreglass spring weighs only 40 kg. This means a reduction in energy consumption or increase in payload.

Risø will work to increase the light output of the laser diodes and help test the system under realistic conditions in Purup-Eskofot's printing house. If development is successful, it will probably establish thermal internal-drum as the dominant CTP technology.

Checking that cancer patients get the right dose

In medical radiation therapy it is important to be able to control the radiation dose that patients receive. To this end Risø has developed a new radiation dosimeter based on a technology known as optically stimulated luminescence (OSL).

The radiation dosimeter is small enough to be placed inside the body, within the affected tissue, where it can measure both the dose rate and the total dose received during therapy. A prototype is ready, and Risø will further develop the radiation method in cooperation with the University of Lund.

Construction technology

Glass fibre springs for train suspensions

A steel suspension spring for a small railway wagon weighs 120 kg, whereas its equivalent in glass fibre composites weighs only 40 kg. Glass fibre springs also retain their properties over their lifetime. Steel springs, in contrast, suffer from ageing that can create a harsh and noisy ride, increasing wear and tear on both wagons and rails.

Risø is taking part in a multinational research project to develop glass fibre springs for rail wagons. Work on the springs themselves is nearly complete, and the next step is to incorporate them in a bogie that will also be made largely from glass fibre composites.

The project is co-ordinated by EUREKA (the European Research Coordination Agency), and includes industrial companies and research institutions from Denmark, the UK, the Czech Republic and Latvia. The Danish company EM Fiberglas A/S is responsible for developing the manufacturing technology and producing the bogies. Risø's job is to characterise material properties such as fatigue, damping and the effect of impact, and to test the finished springs.

Measuring materials properties

The increasing use of advanced materials makes greater demands on testing. In addition, companies who wish to use new materials in their products and processes often require thorough documentation of the materials' properties. As a result, Risø's Materials Research Department has developed new routines for mechanical testing of advanced materials.

The mechanical testing laboratory at Risø is accredited by DANAK. For both routine and advanced tests, the laboratory provides accurate, reliable results with full documentation. Many customers have specialised testing needs, and the service is fully confidential.

Key customers qualify for special contracts that include faster turnaround and lower prices. These customers can also use Risø for in-depth R&D collaboration and as a partner in the process of selecting the best materials for their products.

BOYE KOCH

Microstructure characterisation is a key tool in the study of materials; Risø has two transmission electron microscopes (TEM), three scanning electron microscopes (SEM) and several light microscopes. The microscopes are fitted with advanced analytical equipment, which can be used, for example, to determine the crystallographic orientation or chemical composition of very small areas. Risø has just purchased a new, advanced 300 kV TEM, due for delivery in the autumn of 2001. The microscope will be part of an electron microscope centre for Danish research institutions and industrial companies. Pictured here is Ph.D. student Lars Mikkelsen at one of Risø's scanning electron microscopes.

NORDFOTO

Analysis of the storm of 3 December 1999 shows that there is no need to amend the wind speeds in Danish building standards, but that the specifications of Danish building standards must be adhered to, since by far the most damaged was inflicted on buildings that failed to meet these specifications.

Risk and safety

Danish building standards cope with a 400-year storm

The storm of 3 December 1999 was what is known as a 400-year storm – that is, of an intensity seen on average only once every 400 years. The huge amount of damage it caused prompted calls for Danish building standards to be made more stringent.

To see if this was necessary, Risø worked on a joint project with Elsamprojekt, DMI and consulting engineers Svend Ole Hansen ApS to analyse all the available wind data from 3 December 1999.

The analysis showed that wind speeds during the storm were no more than 15 per cent above the design figures specified in the building standards. This is equivalent to an extra wind load of around 30 per cent. However, buildings that follow the standards are designed to withstand wind loads 50 per cent greater than the predicted maximum.

The conclusion is that for buildings that follow the standard, the probability of damage in a 400-year storm is very low, and so there is no need to amend the standards. It is more important to make sure that all buildings meet the standards, because most of the damage occurred in buildings that failed to meet the standards.

NORDFOTO

By systematically classifying the errors made by air traffic control officers, focus can be directed towards areas where there is the best chance of catching additional errors.

Reducing errors by air traffic controllers

A new system of classifying errors made by air traffic controllers makes it easier to direct specific initiatives towards areas where there is the best chance of averting dangerous situations. Risø developed the system in collaboration with the UK National Air Traffic Service and Eurocontrol, the European Organisation for the Safety of Air Navigation, which funded the project. We normally think of an error

STEEN WEBER

The driver's cab of DSB trains crossing the Øresund bridge. The left panel controls the Danish radio system; the mobile phone on the right controls the Swedish system. Risø researchers are developing a user panel that integrates both systems.

as an act – or a failure to act – that leads to undesirable consequences, and that could and should have been avoided. However, the word "should" can cause problems because it introduces a subjective element to the evaluation.

The new system aims to make the classification of errors as objective as possible. It can be used to analyse individual episodes, but is particularly powerful when applied to groups of episodes, because it can detect patterns in the types of errors made by individual air traffic controllers.

Two radio systems in one for the Øresund link

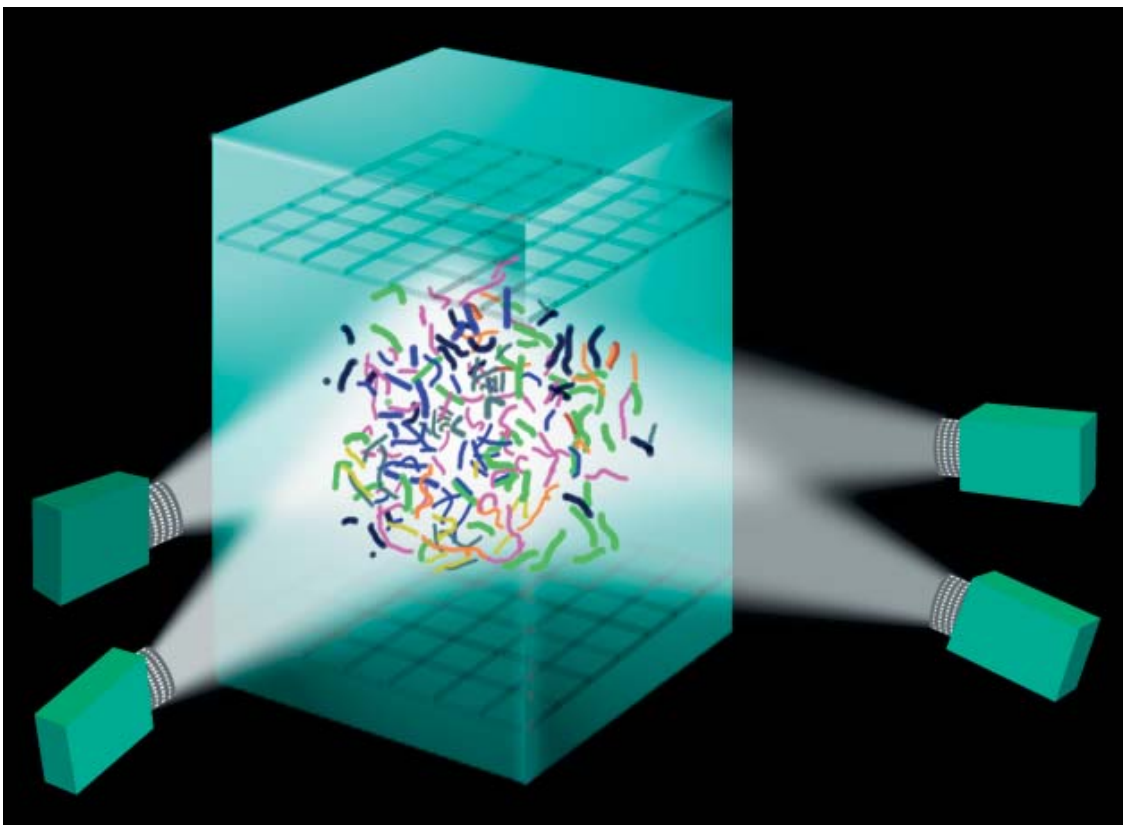
Train drivers on the Øresund link between Denmark and Sweden currently use two different types of radio to communicate with their control centres: the MSR3 system, which is the standard in Denmark, and the Swedish GSM-R system. Now Risø has made the drivers' job simpler by making both radio systems accessible through a single control panel.

At the beginning of 2000, Danish State Railways (DSB) approached Risø's Systems Analysis Department with a request for help integrating the two radio systems. The department already had experience with work on human factors relating to technical systems.

By April 2000 Risø had signed a contract with DSB to develop a prototype linking the two radio systems to a common interface. Work went ahead during 2000 with the co-operation of DSB and SAIT-STENTO Danmark A/S. The final prototype will be evaluated jointly by scientists and users in 2001, and will subsequently be manufactured by SAIT-STENTO Danmark.

Turbulence test benefits risk assessment of hazardous plants

Process plants handling flammable or



Experiments that help with risk assessment of dangerous plants: four synchronised video cameras take stereoscopic images of particles whirling around in a tank. The images are analysed by specially developed software that reconstructs how the particles moved during the experiments.

BOYE KOCH

Risø's Arne Miller is chairman of a working group under CEN, the European Committee for Standardization, which is in the process of revising the standards for the sterilisation of medical devices by means of irradiation.

toxic gases face the risk that a gas cloud may be released in the event of an accident. Risk assessments for these plants therefore rely on computer models of how gas clouds disperse in the air and are carried by the wind. Similar models are used to show how air pollutants disperse from localised sources such as chimneys. Existing models give a good picture of the overall behaviour of the gas cloud, but they have a significant drawback. They ignore air turbulence around obstacles such as buildings, which can cause local pockets of gas to build up. The result could be an unexpected explosion or poisoning incident.

Experiments at Risø have now allowed researchers to calculate the value of an important mathematical constant in the equations describing turbulence. In the future, this should allow more accurate predictions of how gas clouds disperse in the atmosphere.

The experiments use not gases but a tank of water containing two vibrating lattices which create turbulence. Small neutrally-buoyant plastic particles reveal the resulting flow patterns, and their chaotic movements are recorded by four synchronised video cameras. The images are stored in digital form and subsequently analysed using specially-developed software which reconstructs the movement of the particles. The project is supported by STVF.

Environmentally-friendly destruction of discarded ammunition

A project involving Risø has demonstrated that there are environmentally-friendly, safe and cost-effective methods for disposing of old ammunition. The project is co-ordinated by DEMEX Consultants, and the other members are Risø, the Netherlands Organization for Applied Scientific Research (TNO), the Danish Ammunition Arsenal and KommuneKemi, a Danish destruction facility for hazardous waste.

The most promising disposal methods are those that transform ammunition into non-explosive waste at the military sites. Using ordinary methods of transport, this waste is brought to central hazardous-waste incineration facilities. These plants are equipped with flue gas cleaning equipment that removes almost all the hazardous combustion products resulting from the incineration of explosives. Environmental damage is therefore much lower than for ammunition disposal by uncontrolled detonation or burning.

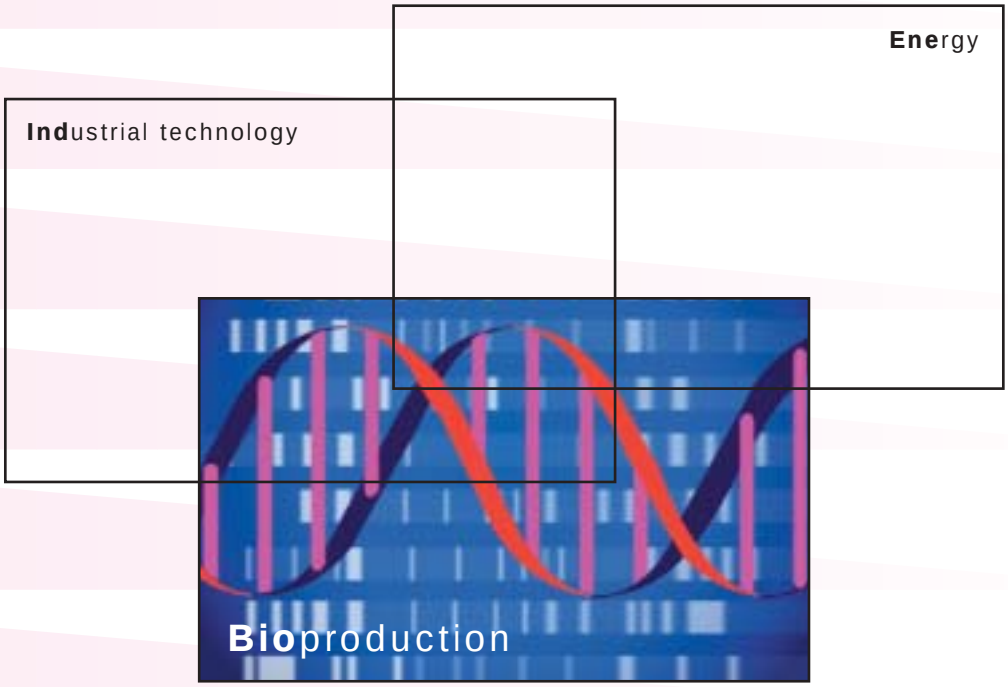
Industrial dosimetry

Checking sterility of medical devices

Wound dressings, sutures and medical devices are commonly sterilised by radiation. Manufacturers of medical devices have to comply with European standards EN 552 and EN 556, which say that radiation doses for sterilisation have to be "traceable and accurate".

The Risø High Dose Reference Laboratory has now been accredited by DANAK for measurements that show whether radiation sterilisation meets the standards. Thanks to agreements between accreditation authorities, certificates issued by Risø are recognised by all the EU member states and by the US authorities – an important advantage for Risø customers.

Risø has the presidency of the committee of the European standards organisation, CEN, which is working on new standards for irradiation of medical equipment.



The use of plants as factories is becoming a key area of research for Risø. Genetic engineering makes it possible to give plants new genes, turning them into eco-friendly factories that use solar energy to directly produce plastics, bio-fuels, sugars and medicines. Food crops, meanwhile, are having to sustain growing populations whilst the total area under cultivation is not increasing. Genetic engineering can increase plants' productivity without compromising on quality, purity or nutritional content.

Genetic engineering

DNA marker technology for plant breeding company

With support from the Danish Academy of Technical Sciences (ATV), Risø has been working with the plant-breeding company Pajbjergfonden on molecular markers for breeding selection.

Traditionally, plant breeders who wish to select for disease resistance have to raise each new generation of plants to maturity and then expose them to the disease in field trials. This is a slow process, and it was a particular problem for Pajbjergfonden because one of the diseases the company is working on is yellow mosaic virus in barley. Since yellow mosaic virus is not found in Denmark, all the field trials had to be conducted abroad.

A better way would be to check each new generation of plants for the particular gene that confers disease resistance. The DNA sequence of the gene is seldom known, however, and without this information the gene cannot be identified in the plants.

An alternative is to use a molecular marker – a small piece of DNA with a known sequence. The marker is inserted into the appropriate chromosome and close to the resistance gene. If the marker and the resistance gene are close enough, they will almost always be inherited together. If a plant carries the marker, it almost certainly has the resistance gene.

Use of molecular markers allows the entire breeding and selection process to be carried out in the laboratory, away from the disturbing influence of environmental factors. This allows breeding to take place all the year round, not just in the growing season, and the selection process is quick because the marker can be identified when the new plant has just two leaves.

Model plants speed up the work of genetic engineering

Risø scientists are working to understand more about the genetic makeup of two so-called model plants: the thale cress *Arabidopsis* and the grass-like *Brachypodium*. The projects have important implications for the breeding of other plants, including the creation of disease-resistant crops.

Model plants are those on which researchers can easily test their theories on the function of genes. A promising gene for disease resistance in barley, for instance, can be quickly tested by inserting it into the model plant. If it seems to work, the scientists can proceed with longer-term experiments on barley plants.

Arabidopsis, a tiny plant that grows wild in the Danish countryside, is an ideal model because it is easy to modify genetically and its seeds can be harvested six to seven weeks after sowing. *Arabidopsis* also has an unusually small genome,

containing just 120 million bases and 26,000 genes.

All the *Arabidopsis* genes have been mapped, but at the moment we know the functions of only a few of them. The next ambitious objective, therefore, is to discover the function of every *Arabidopsis* gene. Risø is a partner in EXOTIC, a large screening project run under the EU's Fifth Framework Programme. EXOTIC aims to discover the *Arabidopsis* genes responsible for flowering and disease resistance.

Risø's laboratories are also home to the first genetically-modified lines of a promising new model plant, *Brachypodium*. A simple little grass, *Brachypodium* has many of the properties required for a good model plant. In particular, it is similar to ryegrass, cereals and other important crops.

Ultimately, scientists would like to know the function of every gene in a plant and understand all the complex interactions that take place within genes. This would allow them to built 'virtual plants' – computer models that could accurately predict the genetic changes needed to improve particular plant properties.

Optical tweezers manipulate cells

Biologists have long dreamed of looking down a microscope and manipulating individual living cells or groups of cells. Thanks to the Optics and Fluid Dynamics Department at Risø, the dream is now coming true. Researchers there are developing a novel multi-beam optical tweezer that out-performs existing instruments.

Conventional optical tweezers use the radiation pressure from a single highly-focused laser beam to trap and study microscopic particles, cells and organisms. The new multi-beam system goes further, allowing the user simultaneously to trap, manipulate or separate one or many cells in a sample.

A simple multi-beam tweezer can be made by shining a wide laser beam at a metal screen containing several holes. This produces several separate light beams, each of which functions as an individual optical tweezer. The drawback is that the light blocked by the screen is wasted.

The Risø scientists have therefore developed an advanced screen that re-

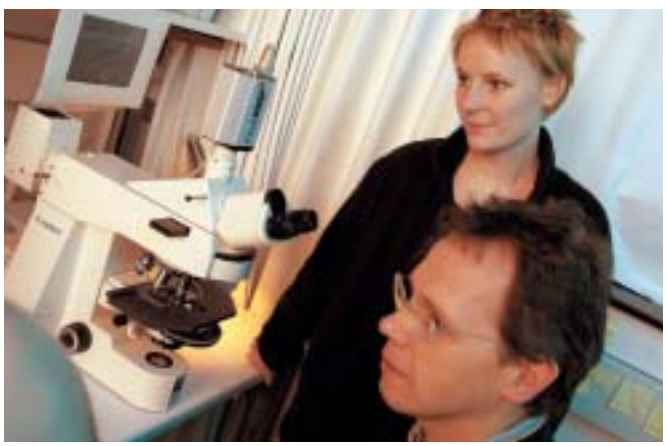
BOYE KOCH

Molecular markers are putting Danish breeders in a position to be competitive at international level. Post doc. Gunter Backes and laboratory assistant Annette Christensen are pictured here, developing new disease-resistance markers for barley.

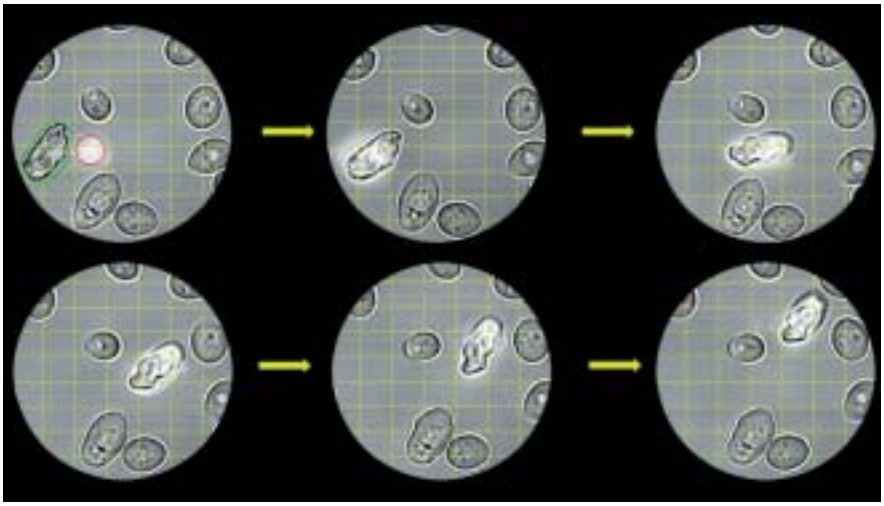
BOYE KOCH

Arabidopsis (thale cress) can be found growing wild in the Danish countryside. It has a simple organisation of genes. It can be harvested 6-7 weeks after sowing and is easy to modify genetically. These factors make it suitable as a model plant, i.e. a plant on which research scientists can make quick and easy tests on the function of genes.

BOYE KOCH



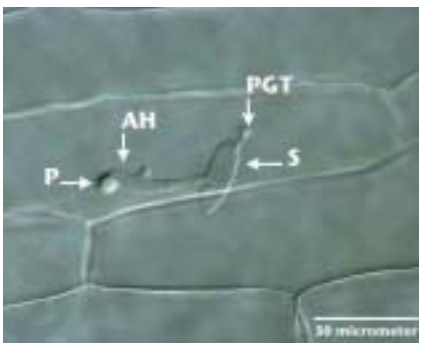
Head of Programme Hans Thordal-Christensen and master student Helene Fast are in the process of studying the disease resistance of plants.



A beam of light catches and moves a yeast cell. The principle is the same as when golden apples are carried on the water jets on Caritas spring water at Gammel Torv square in Copenhagen. The golden apples remain hanging suspended on top of the jet of water as a result of an interaction between opposing forces.

BOYE KOCH

Ph.D. student Kim Burhenne is working on the resistance mechanisms of plant cells; one aspect under investigation is how proteins in barley are involved in its response to stress.



This is how a barley leaf defends itself against attack from a mildew spore: the spore (S) has formed a short primary germ tube (PGT) followed by an appressorial hyphae (AH), from which it has attempted to penetrate the plant cell wall. The attacked barley epidermal cell has prevented this by papilla formation (P), a local reinforcement of the plant cell wall at the point of penetration.

distributes the laser light into five separate beams, rather than blocking it. The technique they use, known as phase contrast filtering, also makes it possible to form and shape the beams as required.

When combined with a dynamic electro-optical element, the system will allow biologists to manipulate individual cells directly from a computer. A mouse will control the tweezer beams and change their shapes so that they match the objects to be trapped.

The scientists at Risø expect the first prototype to be available in a couple of years. A future goal of this work is to miniaturise the optical components so that the entire system fits in a compact module that can be attached to a standard microscope.

Exploiting cellular resistance mechanisms in transgenic plants

Risø scientists are improving the resistance of barley to a fungal disease called powdery mildew. Resistance to powdery mildew traditionally depends on single genes that are specific to particular races of barley. Unfortunately, the powdery mildew fungus often mutates rapidly enough to defeat this race-specific resistance.

However, plant cells also possess other extremely effective resistance mechanisms. For instance, barley can acquire resistance to powdery mildew through previous exposure to a related fungus that does not attack barley, such as a variety of powdery mildew that grows only on wheat.

Risø scientists have found that if an individual plant cell defeats an attack by barley powdery mildew, it becomes completely resistant to subsequent attacks. This induced resistance is also transferred to neighbouring cells. Better knowledge of the mechanisms involved could be used to improve barley's resistance to the fungus.

In fact, the Risø researchers have already created a transgenic barley plant which they expect to be resistant to all varieties of barley powdery mildew. By shuffling components from the barley plant's own genes, they have persuaded cells on the surface of the plant to produce an anti-fungal protein that is

normally only found in the deeper cell layers.

Future experiments will show whether this resistance is effective at all stages of the plant's development, and whether it can be passed on to subsequent generations.

Methods of cultivation

Wheat fungus blows in the wind – but not significantly

During the 1990s, a fungal disease of wheat known as *Septoria tritici* blotch caused increasingly severe epidemics. Without the aid of fungicides, it is estimated that in some years the disease would have cut wheat yields by 20–30%. The epidemics probably have several causes: an increase in the amount of wheat grown, the choice of susceptible cultivars and weather that favoured the growth of the fungus.

The fungus produces two types of spore. One type disperses through splashing by raindrops, and the other disperses on the wind. A recently concluded Ph.D. project at Risø studied in detail the relative importance of the two spore types, and confirmed the presence of wind-dispersed spores in Denmark for the first time.

Mathematical modelling of an epidemic indicated that the splash-dispersed spores predominate. According to the model, wind-dispersed spores would only be expected in significant quantities towards the end of the growing season, too late to influence the epidemic.

Field trials at Risø over three growing seasons confirmed the results of the modelling: although wind-dispersed spores do occur in Denmark, they are not significant in the spread of *Septoria tritici* blotch. This conclusion supports the existing guidelines that tell farmers when to apply fungicides. The guidelines are based on rainfall, and ignore the possibility of wind dispersal in dry weather.

Plant-microbe symbiosis: live and let live

Most plants shelter micro-organisms in their roots, and use nutrients provided by the micro-organisms to keep themselves healthy. Better knowledge of plant-microbe symbiosis, as this is known, could allow us to breed a wider range of crops able to supply their own fertiliser. This is the subject of a research project at the Centre for Plant-Microbe Symbiosis, located at Risø and The Royal Veterinary and Agricultural University (KVL) and set up as a joint venture with the Danish National Research Foundation.

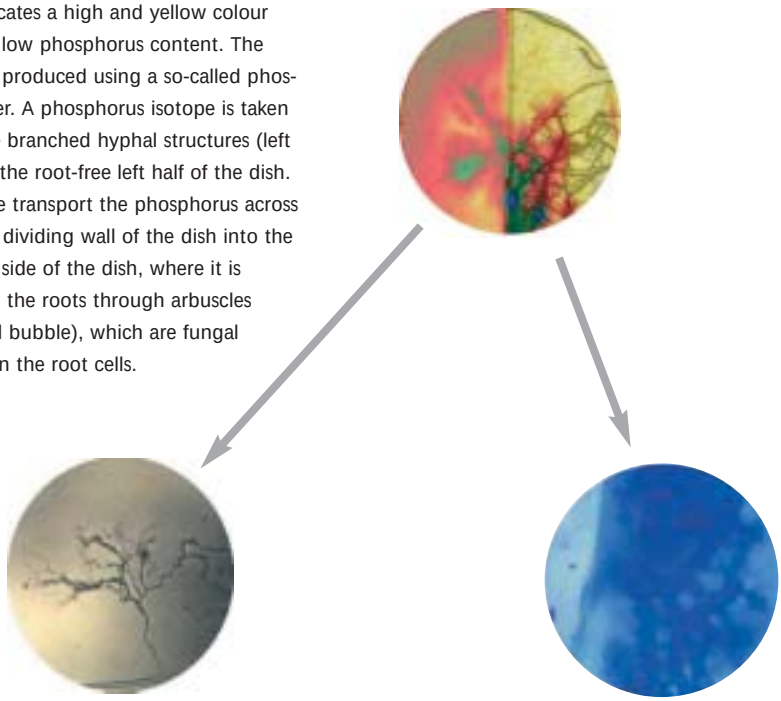
Mycorrhizal fungi can live in symbiosis with most plant species. The fungi invade the plant's root system, from where they extend long threads, known as hyphae, into the surrounding soil. The fungi use their hyphae to take up phosphorus and other nutrients for the plant, which supplies them with sugar in return.

During 2000, the researchers were able to show how the fungal hyphae transfer phosphorus to roots growing in a soil-free gel. They also isolated several of the plant genes responsible for conveying phosphorus directly into the roots of plants that do not have mycorrhizae. The researchers looked at how these genes are affected by the presence of mycorrhizal fungi.

They expected that invading fungi would wipe out the phosphorus-transporting genes, but it turns out that this is

BOYE KOCH

In a new post doctoral project in collaboration with Sejet Plant-breeding, new winter wheat cultivars are being produced with effective resistance to various fungal diseases such as septoria tritici blotch. This is accomplished by utilising new molecular marker methods in plant breeding. Pictured here are industrial post doc Lars B. Eriksen with two wheat breeding lines from Sejet Plantbreeding. The lines are infected with the fungus causing septoria tritici blotch, the line on the left is susceptible and the line on the right is resistant.



A snapshot of phosphorus content and phosphorus transport in mycorrhizae. A blue colour indicates a high and yellow colour indicates a low phosphorus content. The image was produced using a so-called phosphor imager. A phosphorus isotope is taken up into the branched hyphal structures (left bubble) in the root-free left half of the dish. The hyphae transport the phosphorus across the central dividing wall of the dish into the right-hand side of the dish, where it is supplied to the roots through arbuscles (right-hand bubble), which are fungal structures in the root cells.

BOYE KOCH

Senior research scientist Anne Belinda Thomsen and laboratory technician Tomas Fernqvist are pictured here by Risø's new pilot reactor, which can convert biomass (plant remains) into cellulose (in vitro) and water-soluble hemicellulose –

BILLEDHUSET

– both components can readily be converted into ethanol, which can replace MTBE in petrol.

not always the case. This is probably because not all mycorrhizal fungi are equally effective. Any species of mycorrhizal fungus can invade any species of plant, but some combinations work better than others. The most effective symbiosis presumably involves several different species of fungi performing complementary functions.

'Power crops'

Turning straw into eco-friendly fuel

A joint venture between Risø and The Technical University of Denmark (DTU) has built a plant to convert wheat straw into ethanol. The ethanol could form a cost-effective replacement for the environmentally-harmful petrol additive MTBE, the researchers believe. Other waste plant materials besides straw would also be suitable as feedstock.

The first step is to convert cellulose in the plant material into sugars, using water and oxygen at high temperature and pressure in a process known as wet oxidation. Next, industrially-produced enzymes prepare the sugar molecules for fermentation. Then the straw 'soup' is fermented with baker's yeast, and the resulting ethanol distilled off. Finally, any sugar molecules remaining after fermentation are destroyed by thermophilic bacteria discovered in a hot spring in Iceland.

The researchers envisage the process operating alongside a plant producing biogas from animal slurry. The biogas digester would take the waste products of the ethanol plant and turn them into methane. The only effluent from the ethanol plant would then be water containing mineral salts, which could be re-used in the process or used as a fertiliser.

At the same time, waste straw from the slurry, which cannot be used in the biogas plant, would feed the ethanol process. The large amount of water contained in this straw would reduce the amount of water required by the wet oxidation stage, and would also supply essential nutrients to the yeast in the fermentation plant.

The researchers have filed a patent for the entire process, from straw and slurry to ethanol, methane, minerals and water. As well as being a pollution-free way to dispose of existing waste, they believe that the combined plant will be a cost-effective source of ethanol.

Food safety

Organic onions really are different

Are organically-grown vegetables different from conventional ones? For onions and peas, at least, the answer is yes – but researchers are not sure whether this applies to every variety of these crops, or what the nutritional implications are.

With funding from the Research and Development Programme for Food Technology (FØTEK) programme, Risø scientists measured the concentrations of around 60 elements in conventional and organically-grown onions and peas. Growing areas were chosen to include the most common soil types in Denmark. All the conventional farms chosen had used artificial fertiliser to grow their vegetables.

The results were clear: the two farming methods produce onions and peas with distinct elemental profiles. The differences were so obvious, in fact, that the researchers have filed a patent on the subject and hope in the future to develop a practical test to verify the authenticity of produce labelled as organic. It is too early to say, however, whether there is any nutritional difference between organic and conventional produce.

The same project is looking at potatoes and six other vegetables, as well as rye, wheat and oats, collected in collaboration with the Danish Agricultural Advisory Centre. Risø scientists are also working with the Danish Institute of Agricultural Science to compare organic and conventional milk, eggs, pigmeat and pig offal.

In collaboration with The Royal Veterinary and Agricultural University (KVL), Risø researchers are running

BOYE KOCH

Many of the trace elements are present in vegetables at extremely low concentrations. In order to avoid contamination, analysis have to be carried out in a special clean room. Pictured here are Hanne Wojtaszewski and Jette Bruun Nielsen, preparing some vegetables. Lis Vinther Kristensen is seen in the background.

NORDFOTO

There is a clear difference between organically and conventionally grown vegetables. However, it is not known how different varieties may affect the results.

human metabolic balance experiments on two groups of people consuming organic and conventional vegetables respectively. The results will show whether there is any difference in the way the two groups absorb minerals from their diet.

Focusing on natural toxins in crops

Research scientists from Risø and The Royal Veterinary and Agricultural University (KVL) are studying fungal toxins found naturally in crops. Some of these toxins are extremely hazardous to humans, and they can be a serious problem in foodstuffs such as grain stored in warm or damp conditions. They are also a risk in organic produce, which cannot be sprayed to control fungi. Better knowledge of the toxins may ultimately help to develop plant types that are more resistant to fungal diseases.

The study focuses on two fungi and the various toxins they produce. The fungus *Fusarium* attacks the leaves and stems of maize and barley, and so is mainly a problem to animals fed on these. *Fusarium* toxins are also found in maize cobs, grain and flour, however. *Penicillium* mould and its toxins, on the other hand, are mainly found in grain.

Risø has experience in isolating and cultivating these fungi, and possesses the instruments needed to analyse very small samples. The researchers are developing ways to analyse the plants for toxins, and investigating how toxins are exchanged in the soil. They plan to study not only artificially-infected plants, but also to bring in diseased plants from Danish farms.

Certifying radioactivity in Danish food for export

Since the Chernobyl nuclear accident in 1986, Risø has certified the radioactivity of a number of Danish food products for export. Measurements are made on representative samples taken by DANAK and other authorised samplers.

The highest levels of radioactivity are seen in fish from the Baltic Sea, which was heavily contaminated by Chernobyl fallout. For other Danish food products, contamination levels have decreased steadily and are now below 5 Bq/kg ^{137}Cs.

Higher levels of radioactivity are sometimes seen, and they invariably show that the sample is adulterated with material originating outside Denmark. This may be one reason that export certificates are still in use 15 years after Chernobyl.

BOYE KOCH

Advanced analysis methods are required to analyse fungal toxins in soil and plant matter. Shown here is a new technique, SPME (solid phase micro extraction).

Knowledge, competences and human resources

Educating scientists

14 Risø students received their Ph.D.s in 2000. 75 Ph.D. students, corresponding to a total of 67 person-years, were associated with Risø in 2000. 41 of these students received scholarships funded jointly by the Danish Research Academy and Risø; of these, five were associated with the graduate school in Biophysics and four with the graduate school in Non-linear Science. Seven others were financed by the Engineering Science Centre, while the remainder were supported by other means. 61 postdoctoral scholarships at Risø, including thirty-five international post docs, corresponded to 61 person-years.

Ph.D.s awarded in 2000

Wind Energy and Atmospheric Physics Department
Alfred K. Joensen, M.E., The Technical University of Denmark (DTU)
Gregor Giebel, M.Sc., Technische Universität, Munich
Alexandre de Lemos Pereira, M.Sc., The Technical University of Denmark (DTU)

Optics and Fluid Dynamics Department
Peter Lodahl, M.Sc., Aarhus University
Thomas Nikolajsen, M.Sc., Aalborg University
Birgitte Testrup Nielsen, M.Sc., University of Copenhagen

Plant Biology and Biogeochemistry Department
Lars Eriksen, M.Sc. (agricultural science), The Royal Veterinary and Agricultural University

Materials Research Department
Søren Fæster Nielsen, M.Sc., University of Copenhagen

Condensed Matter Physics and Chemistry Department
Johannes Reynisson, M.Sc., University of Iceland
André Faldt, M.Sc., University of Copenhagen

Systems Analysis Department
Haldor Palsson, M.E., The Technical University of Denmark (DTU)
Jørgen H. K. Jacobsen, M.A. (political science), University of Copenhagen
John Callaway, M.Sc., Tilbury University

Nuclear Safety Research Department
Jakob Helt-Hansen, M.Sc., University of Copenhagen

BOYE KOCH

The 2000 DOPS prize was awarded to Jesper Glückstad (right) of Risø for his research in the field of adaptive optics and phase contrast. The prize was presented by the chairman of DOPS, Bjarne Tromborg.

Prizes, appointments and honours in 2000

Materials Research Department
Niels Hansen, Dr.techn., Head of the Materials Research Department until the end of 2000, was presented with the Poul Bergsøe Medal at the general meeting of the Danish Metallurgical Society.

Condensed Matter Physics and Chemistry Department
Senior research scientist Jan Skov Pedersen, Ph.D., defended his Danish doctoral thesis at KU at the end of March. The subject was measurement of non-rigid materials using neutron scattering. He took up a professorship at Aarhus University in August 2000.

Optics and Fluid Dynamics Department
Senior research scientist Jesper Glückstad, M.E., was awarded the 2000 DOPS prize. Specialist researcher Paul Michael Petersen, M.E., was awarded the Senior prize of the Danish Optical Society (DOPS). Research specialist Jørgen Schou, M.Sc., was appointed associate professor of physics at the Faculty of Science and Engineering at the University of Southern Denmark (SDU), for the period 1 September 2000 to 31 August 2005.

Nuclear Safety Research Department
Senior research scientist Lars Bøtter-Jensen, M.E., defended his Danish doctoral thesis at KU in November 2000.

Plant Biology and Biogeochemistry Department
Scientist Iben Ellegaard Bechmann, M.E., received the *Valborg og Edith Larsens* grant for the furtherance of research opportunities for women.
Senior research Professor Erik Steen Jensen, Ph.D. (agricultural science), Dr. agro., received the *Fabrikant Ulrik Brinch og hustru Marie Brinch* grant.

Networking through Risø's graduate schools

The Graduate School in Nonlinear Science is a collaboration between Risø, The Technical University of Denmark and the Niels Bohr Institute at the University of Copenhagen. Staff from Novo Nordisk are also represented on the steering committee. The School is sponsored by the Danish Research Training Council under the Danish Research Council.

In 2000 the school attracted 30 foreign Ph.D. students, some of whom attended courses and conferences while others worked in long-term collaborations with Danish students. In addition, 35 Danish Ph.D. students attended courses and lectures held by Danish and international experts. More than 50 visiting professors and scientists acted as lecturers and supervisors. This diversity in both students and lecturers means that the Graduate

School in Nonlinear Science provides students with networking opportunities that will be valuable to their future careers.

Risø is also the prime mover in the Danish Research Agency's Graduate School of Biophysics, a collaborative project between the Niels Bohr Institute at the University of Copenhagen, the August Krogh Institute, The Technical University of Denmark and the Royal Veterinary and Agricultural University.

In 2000 the School had 16 Ph.D. students, of whom three came from abroad, and 22 guest teachers. In 12 months at the School one Hungarian guest student has achieved results that are so promising that he has been offered a permanent position when he completes his Ph.D. His work has already resulted in two articles and one patent application.

With the help of the Centre National de la Récherche Scientifique (CNRS) in France and with maximum support from the EU, the School held a combined course and workshop entitled *Medical Applications of Hyperpolarised Gases* that attracted 41 students from all over the world.

Collaborating on education in biomedical optics

The Centre for Biomedical Optics and New Laser Systems (BIOP) is a collaborative programme for research and education in the biomedical applications of lasers. The participating scientists come from The Technical University of Denmark and Risø, while medical doctors from the Herlev Hospital at the University of Copenhagen and Marselisborg Hospital at the University of Aarhus are also associated with the Centre. In spring 2000 BIOP held a master course at The Technical University of Denmark with 25 participants.

Ph.D. students learn to manage research

The role of research is changing. It is no longer enough just to publish reliable results; society increasingly expects research to perform functions such as generating prosperity. This requires closer interaction between research institutions, companies, public authorities and non-academics.

During 2000 Risø conducted a Ph.D. course in the management of research and innovation. The course attracted 12 Ph.D. students from Risø and one from Copenhagen University Hospital. It was run in collaboration with the Copenhagen School of Business as part of the REMAP (Research Management under Rapid Change) research project, which also involves the Danish Institute for Studies in Research and Research Policy and six Danish companies.

The course dealt with how the students' own research relates to the needs of public authorities, private companies and society as a whole. It also aimed to make the students more aware of alternative careers, such as in industry or as high-tech entrepreneurs.

Industrial scientists forge links with companies

Industrial scientists can act as valuable links between their companies and Risø. The companies get access to sophisticated analytical equipment and help with interpreting experimental results, while Risø learns about real industrial problems. The personal nature of the collaboration also strengthens the relationships between Risø and its customers.

One example of this collaboration with industrial scientists concerns Roulunds, a company that manufactures friction materials for vehicle brakes. In a recent project with Roulunds, Risø worked alongside the Danish Technological Institute and The Technical University of Denmark (DTU) to develop improved brake materials.

Another project concerned the manufacture of durable iron-based composites for machine parts subject to severe wear, such as components for machines used in agriculture and forestry. Risø, Danish Steel Works Ltd., Dan Spray, the Danish Technological Institute and The Technical University of Denmark (DTU) were involved in this project. New composite materials produced in Risø's spray forming plant proved to resist wear three times better than the purely metallic materials currently used. The new materials can be shaped using normal forging methods.

Students from The Technical University of Denmark (DTU) and other higher education institutions can take summer jobs in Risø's Materials Research Department. Over the last three years, 15 students have supplemented their education by working on projects in the Depart-

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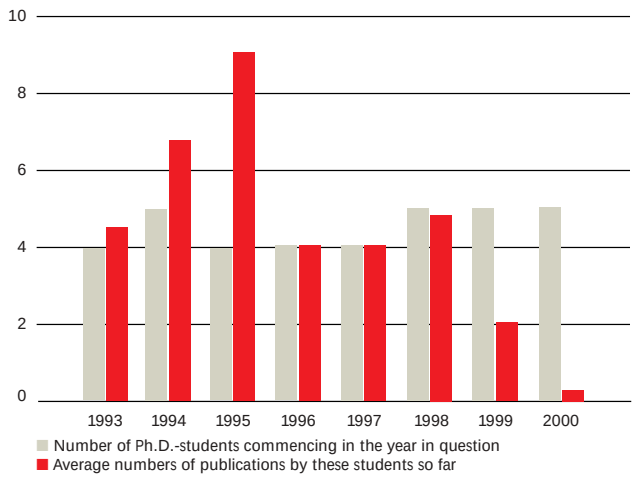
Getting paid to learn: Jesper Holm, Jan Høgsberg, Ann Marie Barwaker, Casper Thorning, Jens Høgh and Lars Rindorf are all summer students at Risø's Materials Research Department



ment. Three of the students were able to use their summer projects as actual coursework, and two others used their summer jobs as jumping-off points for new projects when they returned to their universities. Several of the projects attract direct sponsorship from industry.

Ph.D. students contribute significantly to Risø's list of publications

The Materials Research Department has been looking at the number of international publications resulting from its Ph.D. projects. The graph refers to Ph.D. projects started since 1993 and completed within the last five years, as well as those yet to be completed. For the Ph.D. students starting in each of the years in question (grey bars), a count was made of the total number of publications so far; this number was then divided by the number of students (red bars).

Employees and management

Employee satisfaction survey

Risø has carried out its first-ever employee satisfaction survey. Following the survey, each department prepared its own action plan to ensure high levels of employee satisfaction in the future. These action plans will be followed up in 2001. One particular point that came to light in the survey was the need to review how Risø's employee development interviews are carried out. During 2001 we will introduce a new framework for employee development interviews, along with the necessary training.

Shared values at the Danish Polymer Centre

Risø is entering into increasing numbers of joint ventures involving closer collaboration with industry and universities. One example is the Danish Polymer Centre, in which Risø and The Technical University of Denmark (DTU) have pooled their resources.

As part of its ambitious vision, the Danish Polymer Centre aims to grow rapidly. The Centre's managers believe that the ability to help different cultures work together is essential to this growth. With this in mind, Risø's Human Resources Department applied for and received a grant of DKK 400,000 from the Development Fund for a pilot project to create shared values for the Danish Polymer Centre. The project is due to finish in 2001.

Home study increases IT skills

Halfway through 1999, Risø offered 165 employees home-study courses that would lead them to a 'driving licence' for personal computers (PCs). The 18-month home-study project went a long way towards achieving the desired increase in IT skills at Risø, and its success prompted a follow-up project in 2001. The new project has no restriction on the number of participants, and 76 employees have enrolled.

Using existing resources: the WER project

A project known as With Existing Resources (WER) now being developed at employee, corporate and management levels within Risø is operated by the Nuclear Facilities Department in collaboration with the consultancy firm RMS, the Roskilde AMU centre and the Confederation of Danish Industries. Participating companies apart from Risø are Chr. Hansen, at its Roskilde and Avedøre sites, and Microtronic.

How the closure of DR3 will affect employees

By 2000 it was clear that the closure of DR3 would shortly become a reality. With this in mind, Risø set up a working party to discuss the situation and come up with proposals for fair treatment of the staff. One result of this is that everyone affected by the closure will have a guaranteed income for 12 months. A further transitional project will be carried out during 2001.

Personnel 1997 – 2000 (Man years)

	1997	1998	1999	2000
Research departments				
Heads of departments	7	7	7	6
Heads of programmes and tasks	53	40	40	42
Research professors	-	-	-	2
Research specialists	-	3	6	7
Senior scientists and senior advisors	109	124	125	123
Researchers	46	42	41	44
Project researchers and Post docs	49	50	56	51
PhD students	55	57	65	71
Academic transfer arrangement	5	7	2	2
Academics on new salary system	32	32	43	45
Other staff on new salary system	184	198	192	190
Total research departments	**540**	**560**	**577**	**582**
Nuclear facilities	**82**	**77**	**78**	**76**
Infrastructure				
Technical department	146	123	114	104
Administration and safety	96	71	69	67
Trainees, apprentices	35	31	27	24
Total infrastructure	**277**	**226**	**211**	**194**
Total Risø	**899**	**863**	**866**	**852**

Organisation and management

Board of Governors

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Danfoss A/S
Chairman of the Board

Povl Skovgaard, Director
Vice Chairman of the Board

Per Buch Andreasen, M.D., Dr. Med. Sc.
Copenhagen District Hospital, Gentofte

Professor Knut Conradsen, Vice Rector
The Technical University of Denmark

Jørgen Elikofer, Management Secretariat
Danish Metalworkers' Union

Agnete Gersing, Head of Department
Ministry of Finance

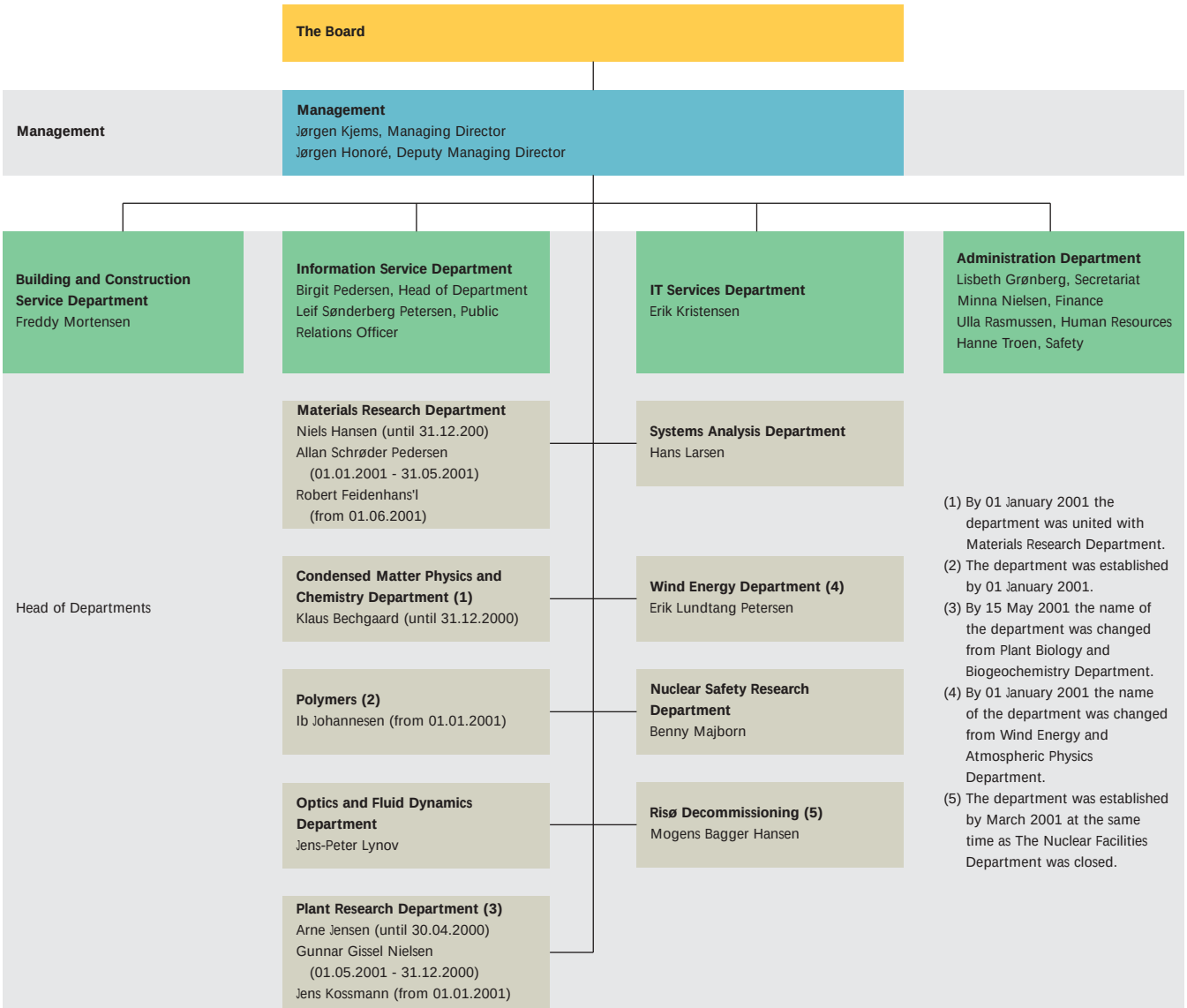
Torben Mikkelsen, Senior Research Scientist
Risø National Laboratory
Elected by Risø staff

Jens Olsson, Research Technician
Risø National Laboratory
Elected by Risø staff

Birte Skands, Development Manager
VIKAS A/S

Annette Toft, Head of Department
Danish Agriculture Council

Lisbeth Grønberg, LL.M.
Risø National Laboratory, Secretary of the Board



(1) By 01 January 2001 the department was united with Materials Research Department.
(2) The department was established by 01 January 2001.
(3) By 15 May 2001 the name of the department was changed from Plant Biology and Biogeochemistry Department.
(4) By 01 January 2001 the name of the department was changed from Wind Energy and Atmospheric Physics Department.
(5) The department was established by March 2001 at the same time as The Nuclear Facilities Department was closed.

Experimental facilities

DR3 closes but research will continue in Switzerland

With the closure of the DR3 reactor in September 2000, Risø's materials researchers lost the source of neutrons that had enabled them to look inside materials to study their structures, magnetic properties and dynamics at the molecular and atomic level.

During the autumn, Risø investigated other European materials reactors in an effort to find somewhere suitable for continuing this type of materials research. Risø's materials researchers are recognised as attractive partners for many similar groups around the world, and many European neutron research centres invited the Risø group to expand collaboration with their respective institutions.

After due thought, Risø signed an agreement with the Paul Scherrer Institute (PSI) in Switzerland. The new neutron source at PSI, of the type known as a spallation source, is not a nuclear reactor, but its characteristics so strongly resemble those of a reactor that it will allow many of Risø's neutron scattering instruments to be used without modification.

According to the agreement, Risø will initially be able to deploy two of its most advanced instruments at PSI: the brand new RITA (Re-Invented Triple-Axis Spectrometer), expected to be operational in spring 2001, and SANS (Small-Angle Neutron Scattering Instrument), expected to be operational from the beginning of 2002.

The instruments will be transferred to PSI on condition that Danish neutron scattering scientists have access to them and other instruments belonging to PSI for a specified number of weeks each year. Risø research scientists will still be able to contribute ideas for new instruments, even though they will not be responsible for construction, now that Denmark's Large-Scale Experimental Facility is no longer operational. In this way a first step towards securing the continuity of Danish neutron research is assured.

Risø will probably be able to sell the remaining instruments from DR3. Scientists at reactors in Sweden and Norway are among those who have expressed interest, and negotiations are under way. The terms of any deals may include access for Danish researchers to these facilities abroad.

There are plans to transfer a number of Risø's neutron spectrometers to the Paul Scherrer Institute in Switzerland following the closure of the DR3 training reactor at the end of the year 2000.

PAUL SCHERRER INSTITUT

Publications

Risø's publishing activities

Risø's research generates papers and articles in international journals, research reports and other publications. This publishing activity is the main way in which Risø scientists transfer technology to industry and exchange knowledge with their counterparts in other research institutions, both in Denmark and abroad.

Articles, books, reports and conference papers

Risø maintains a database of information on its own publications and lectures. The Risø website (www.risoe.dk) allows users to search the database and to download publications from Risø's own series of reports, all of which are published electronically as well as on paper. Information on Risø publications is also available from the Danish National Research Database.

Highlighted below are various aspects of publishing activities in 2000, based on information from the publications database.

Risø articles in ISI Source Journals

As a supplement to the citation analyses prepared from the in-house publications database (Figures 1–4), Risø uses an Institutional Citation Report (ICR) from the Institute for Scientific Information (ISI). The ICR database refers to articles in ISI's Source Journals in which Risø is given as the author's address. ISI Source Journals comprise more than 4,000 international publications in the natural sciences and technology, and around 3,000 in the humanities and social sciences. Most of Risø's international articles are published in ISI Source Journals.

Figure 1: Publications and lectures 1996–2000, arranged by type

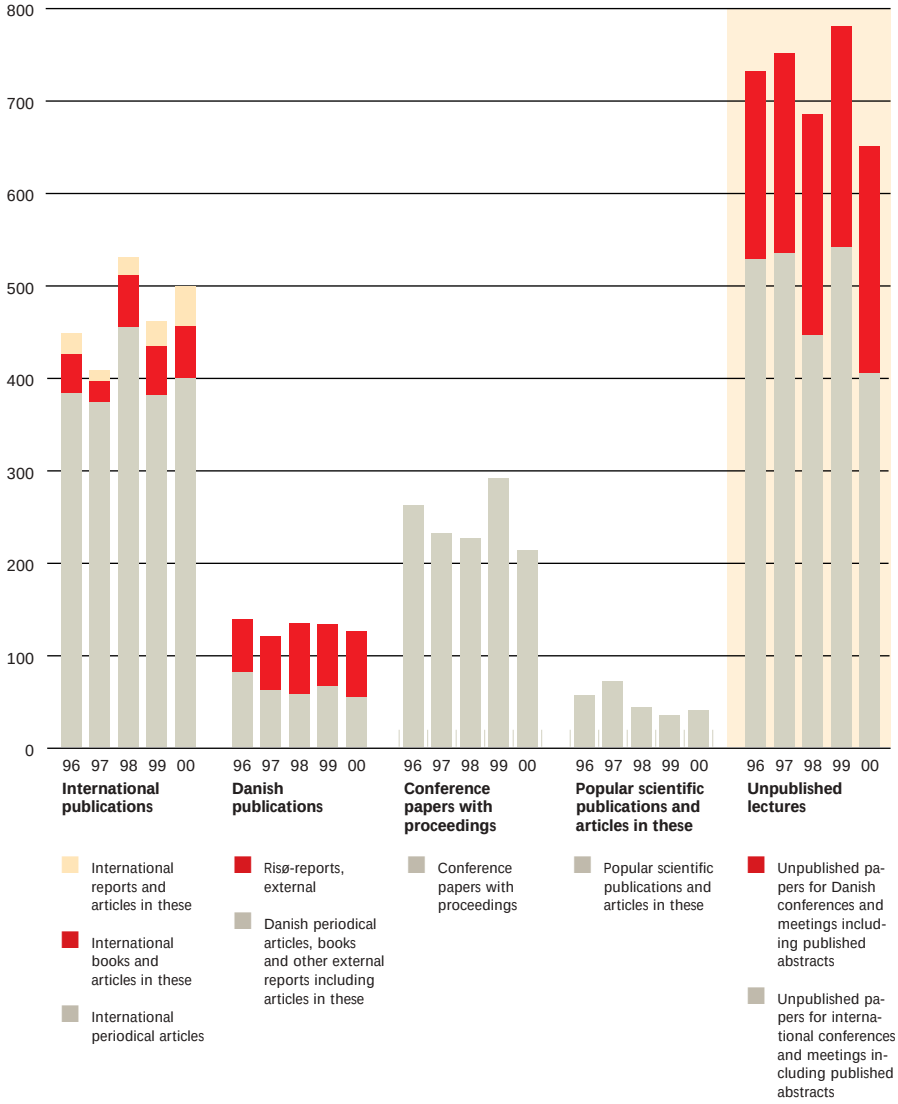


Figure 2: Publishing totals 1990-2000 for the publication types referred to in Figure 1

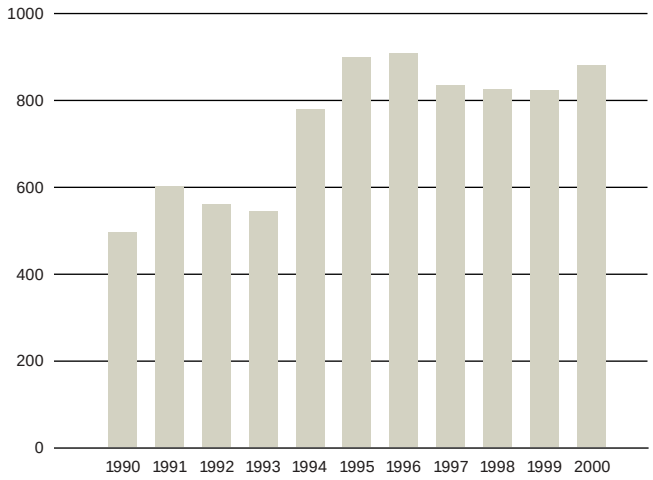


Figure 3. Publications in 2000 by programme area and type

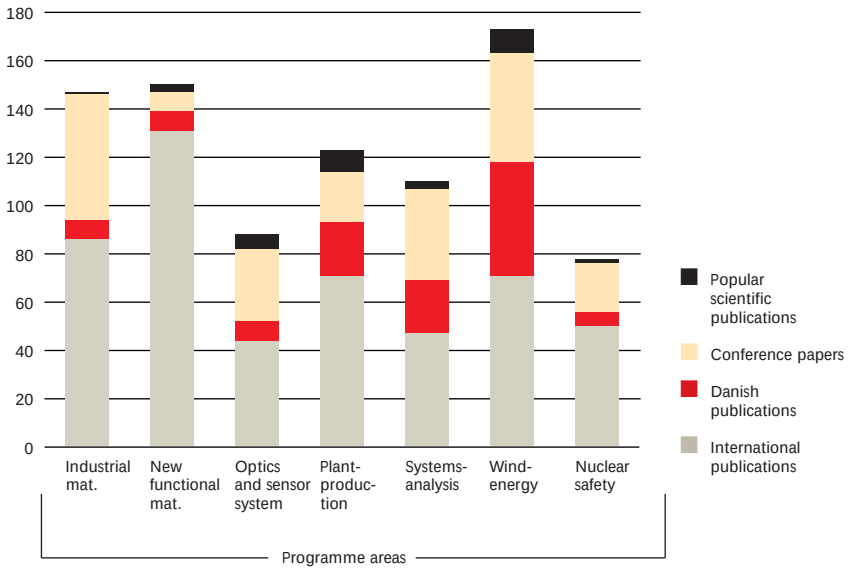


Figure 4: Number of publications in 2000 with Risø as the sole author, main author or co-author. The publication types correspond to those of Figure 1.

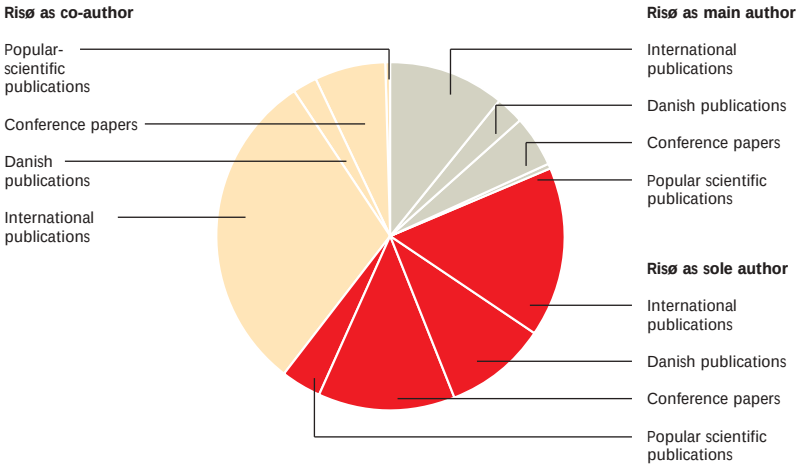


Figure 5: Number of Risø's articles in ISI Source Journals 1985–1999

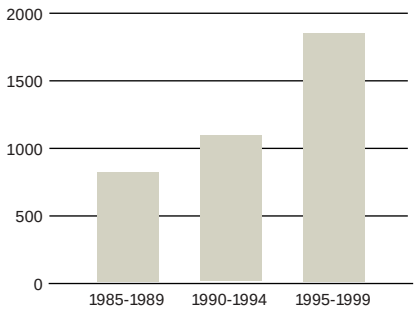


Figure 6: Number of citations to Risø's articles in ISI Source Journals, for the same five-year periods within which the articles were published

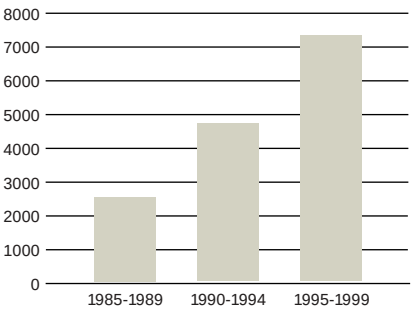
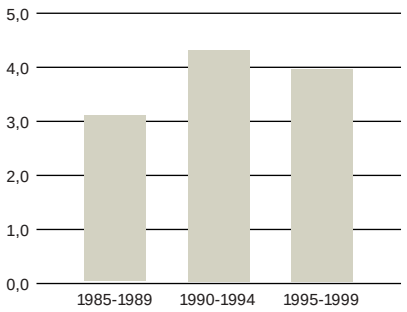


Figure 7: Average number of citations per Risø article, for the same five-year periods within which the articles were published



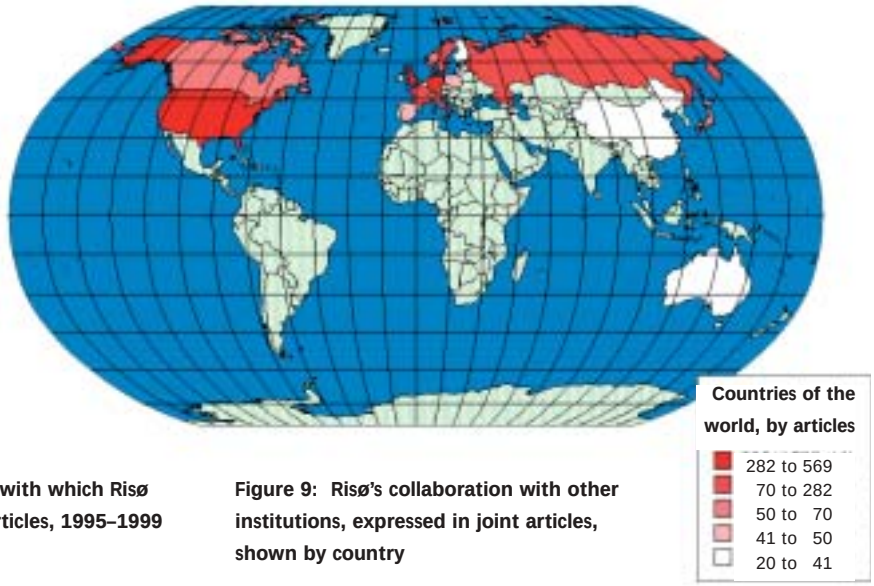


Figure 8: The 25 institutions with which Risø jointly published the most articles, 1995–1999

Based on the information about authors' institutions published in ISI Source Journals, the 25 institutions with which Risø published the most articles during 1995–1999 are:

Institution	Articles
The Technical University of Denmark	112
University of Copenhagen	77
Russian Academy of Sciences	51
Ford Motor Company	49
KFA Jülich GmbH	43
University of Oxford	43
University of Minnesota	32
Danish National Environmental Research Institute	30
Aarhus University	28
University of Hamburg	28
ETH Zurich	27
The Royal Veterinary & Agricultural University	27
Weizmann Institute of Science	25
Inst Max Von Laue Paul Langevin	24
Niels Bohr Institute	23
Rutherford Appleton Laboratory	23
At&T Bell Labs	22
Brookhaven National Laboratory	21
DESY	21
European Synchrotron Radiation Facility	19
Chalmers University of Technology	18
Hahn Meitner Inst Berlin GmbH	17
University of Toronto	17
Lund University	16
Oak Ridge National Laboratory	16

Figure 9: Risø's collaboration with other institutions, expressed in joint articles, shown by country

Based on the institutional information provided in respect of the authors of articles appearing in ISI Source Journals, the countries with wich Risø has jointly published more than 20 articles in the period 1995-1999 are shown.

Country	Articles
USA	569
Denmark	518
Germany	375
United Kingdom	282
France	160
Sweden	123
Russia	97
Italy	70
Canada	61
Japan	60
The Netherlands	50
Norway	50
Switzerland	49
Israel	47
Spain	43
Poland	41
Australia	35
Belgium	30
Finland	28
China	20

Patents and licences

Patent applications and inventions taken over by Risø from its employees during 2000, of which approx. one-half are covered by agreements regulating commercial exploitation.

Title/application	*Inventors*
A method of operating a turbine Optimises turbine output.	Lars Henrik Hansen
A wheat bran Phytase Makes it possible to develop wheat that causes humans and animals to absorb more phosphate, protein and minerals from wheat-based foods. Potential reduction in pollution, and improved nutrition in developing countries.	Søren K. Rasmussen, Katja S. Johansen and Mikael B. Sørensen
Solid oxide fuel cell as well as a method of manufacturing said oxide fuel cell Further development of fuel cells.	Carsten Bagger
Anchoring of SOFC electrodes Further development of fuel cells.	Søren Primdahl and Søren Linderoth
Optical amplification in coherent optical frequency modulated continuous wave reflectometry Improved clinical diagnostics using new optical methods.	Peter E. Andersen (the invention was a result of collaboration with The Technical University of Denmark (DTU); the co-in ventors were Anders Bjarklev and Andreas Tycho)
A computer input device with optical detection means Optical reading of the movements of a sphere, used to develop a new PC mouse.	Steen G. Hanson and Rene Skov Hansen
Polymer composite product, a process for the manufacture thereof, and use of the product Increases the strength of moulded plant fibres	Tom Løgstrup Andersen and David Plackett
Forming process of amorphous alloy material Manufacturing method for thin and lightweight materials	Nini Pryds, Morten Eldrup, Søren Linderoth and Allan Schrøder Pedersen
Coupling elements for surface plasmon resonance sensors Sensor chip using holographic principles that can be used to measure water quality	Henrik Chresten Pedersen together with an employee of a private-sector company.
Holographic optical element feedback system Improves the coherency properties of a laser system	Paul Michael Petersen
Laser drum technology Improved diode laser	Paul Michael Petersen
Polarisation encryption/decryption module Compact opto-electronic encryption module for data communications	Jesper Glückstad og Paul C. Mogensen
Reverse symmetry waveguide for optical biosensing New optical sensor for measuring biochemical substances in liquids. Provides cheaper and easier small-scale quantification of DNA and detection of protein, bacteria and cells	Henrik Chresten Pedersen, Robert Hovarth, Lars Lindvold and Niels B. Larsen
Suspension of ammunition A gel that renders ammunition harmless, with applications for transportation and decommissioning	Frank Markert and an employee of a private-sector company
Single-molecule fluorescence sensor New method for monitoring and identifying material properties	Ib Johannsen, Mikkel Jørgensen and Rolf Berg

Overview of assignment and license agreements made in 2000 relating to commercial exploitation of intellectual property rights (IPR).

Patent or patent application	*Assigned or licensed to*
A prosthetic device	Cartificial A/S. IPR was assigned in return for shares in the company
Method and apparatus for determining the rate of angular rotation of a rotating object	Kanitech International A/S
A computer input device with optical detection means	Kanitech International A/S
Coupling elements for surface plasmon resonance sensors	Vir A/S. IPR was assigned to the company
Laser drum technology	Purup-Eskofot A/S
Solid oxide fuel cell as well as a method of manufacturing said oxide fuel cell	Haldor Topsøe A/S
Anchoring of SOFC electrodes	Haldor Topsøe A/S
Novel physically functional materials	Optilink AG. IPR was assigned to the company
Optical storage medium	Optilink AG. IPR was assigned to the company
Holographic smart card	Optilink AG. IPR was assigned to the company

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Finance

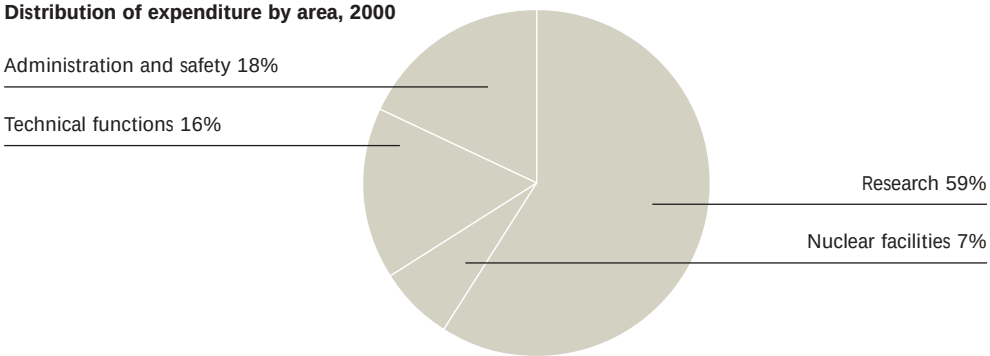
Operating statements for Risø National Laboratory				
DKK million, excluding VAT				
	1999 accounts	2000 accounts	Budget 2001	Notes
Government appropriations	264.3	274.4	284.9	
Contract earnings	244.9	242.6	281.0	
Total income	**509.2**	**517.0**	**565.9**	
Wages and salaries	290.5	297.6	314.2	
Operation costs	180.3	182.0	202.3	1
Investments	38.0	57.2	69.9	2
Total expenditure	**508.8**	**536.8**	**586.4**	
Balance	**0.3**	**(19.8)**	**(20.5)**	3

Note 1 No loads of spent reactor fuel were dispatched in 2000, whereas two loads were dispatched in 1999. Provision has been made in the 2001 budget for the dispatch of one load of spent reactor fuel.

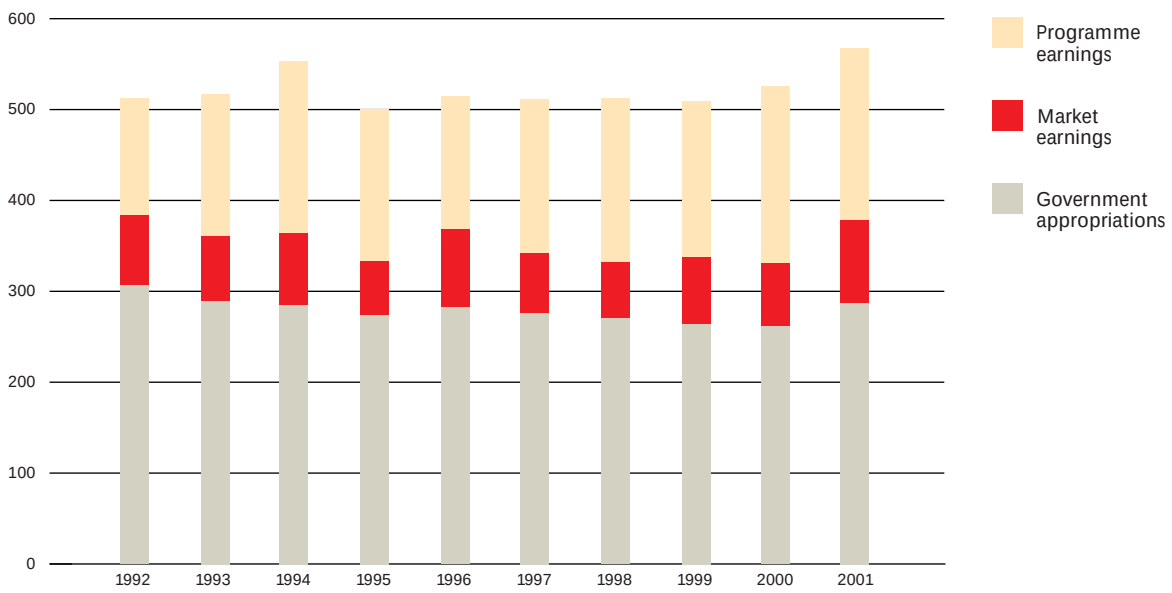
Note 2 Of which DKK 31.7 million were plant and equipment expenses in the National Accounts for 2000 (DKK 8.2 million in 1999).

Note 3 Provision has been made in the 2001 budget for expenditure in respect of the nuclear facility (approx. DKK 38 million). This expenditure is expected to be transferred in 2002 to Dansk Dekommissionering (Danish Decommissioning), which will assume the task of decommissioning nuclear operations at Risø.

Distribution of expenditure by area, 2000



Income development (2000 – price level, DKK million)



Balance sheet at 31 December 2000

DKK million at current prices

	1999 accounts	2000 accounts	Notes
Assets			
Tangible fixed assets	227.7	248.8	1
Current assets			
- Cash and deposits	35.1	80.7	2
- Accounts receivable	115.6	140.6	3
Total assets	**378.4**	**470.1**	
Liabilities			
State financing of Risø's activities:			
- State financing of plant and equipment	227.7	248.6	
- Accumulated result from operations	14.3	–5.4	
- State financing of other assets	77.6	90.5	2
Short-term debt	58.8	136.4	4
Total liabilities	**378.4**	**470.1**	

Note 1 The book value of the fixed assets at the end of 2000. This is made up of accumulated acquisitions, reduced by disposals and depreciation. Depreciation is calculated at 5% using the straight-line method.

Note 2 Risø's balance of DKK 75.3 million with the National Bank (DKK 30.6 million in 1999) is included in the figure for cash and deposits. As a result of the accounting method applied for independent liquidity, this balance is also included on the balance sheet as part of the state financing of other assets.

Note 3 Included in the total is accrued income of DKK 39.4 million from projects to be invoiced in the following financial year (EU projects etc.) The figure was DKK 38.6 million in 1999.

Note 4 The comparatively large increase from 1999 to 2000 is due primarily to an increase in payments with reference to goods and services to be supplied at a later date.
This item totalled DKK 89.4 million at the end of 2000 compared to DKK 28.3 million at the end of 1999.

Environment

The Green Account summarises Risø's position in environmental and safety matters, through information on:

- compliance with legislation and approvals relating to safety and the environment (external environment, working environment, health, fire, emergency preparedness, nuclear safety and radiation protection);
- consumption of resources;
- emissions to the environment; and
- health effects on staff, and staff absences due to illness.

The Green Account has been part of Risø's Annual Report since 1996. Since 1999, the information published there has been supplemented with further environmental and safety information on the Risø website.

Risø's philosophy is that safety work should be preventative, that safety is a natural part of everyday work, and that there is a definite link between management responsibility and responsibility for safety. An annual process of 'working environment mapping' ensures that Risø's plans are regularly updated to include major safety improvements.

Safety work in Risø's individual departments is a compulsory part of the annual assessment that each department undergoes. Since 1998, an internal health and safety report has been prepared for each department and for Risø as a whole.

The Green Account shows that all Risø's emissions to the environment, and the resulting effects on staff, meet the relevant statutory limits or, where legislation does not apply, appropriate 'good practice' values. Several fields (violations of Conditions for Operating Nuclear Facilities, special reports, industrial accidents reported and fires) show improvement in 2000 compared with 1999.

The level of safety at Risø is generally good, but in accordance with safety policy, we are continuously trying to improve in this area.

Risø's Green Account

Environmental statistics for Risø National Laboratory	1999	2000	Environmental key figures Risø 2000		Statutory or *typical* value [a]
Statutory and legal events					
Injunctions from the environmental authorities	0	0			
Petitions from the environmental authorities	0	0			
Injunctions from the Labour Inspection Service	0	0			
Guidance from the Labour Inspection Service	1	0			
Instances of exceeding limit values for sewage	0	0			
Violations of Conditions for Operating Nuclear Facilities	5	1			
Special reports on the nuclear facilities	3	2			
Health and safety					
Absence due to illness [b] (days lost)	5.0	5.6	5.6		*8.6 Days lost due* [c]
Internal accidents reported	17	13			*to illness*
Injuries treated in Risø's emergency room [d]	35	26			
Industrial accidents reported to the Labour Inspection Service	9	6	7 per 1,000 [e]		*9 per 1,000* [f]
Industrial accidents reported to the National Board of Industrial Injuries [g]	6	3			
Fire alarms		9	21		
Fires / suspected fires	4	2			
Maximum individual effective radiation dose [h] (mSv)	7.4	8.0	8.0	mSv	20 mSv [i]
Annual collective effective radiation dose [j] (person-mSv)	169.7	150.8			
Utilities consumption					
Water (m^3)	63,822	75,390	81	m^3/PE	*62 m^3/PE* [k]
Electricity (MWh)	11,613	10,273	82	kWh/m^2 [l]	*78 kWh/m^2* [m]
Heating (MWh)	11.138	10,514	172	kWh/m^2	*176 kWh/m^2* [n]
Natural gas [o] (m^3)	1,750,439	1,917,269			
Coolants [p] (kg)	212	122			
Atmospheric emissions					
^{41}Argon (from DR3) (GBq)	16,000	3,180	}		
Tritium (tritiated water vapour from DR3) (GBq) [q]	16,000	27,700	}		
Iodine (GBq)	Negligible	Negligible	} 0.46 µSv/year [r]		200 µSv/year [s]
^{14}C carbon dioxide (from the waste management plant) (GBq)	4	0	}		
ß-activity (GBq)	Negligible	Negligible	}		
Sewage etc.					
Sewage (m^3)	55,000	62,000	62,000	m^3	182,500 m^3 [t]
Chemical oxygen demand, COD (kg)	1,716	2,108	34.0	mg/l	
Biochemical oxygen demand, BI_5 (kg)	160	124	2.0	-	15 mg/l
Suspended state (kg)	242	279	4.5	-	20 -
Total nitrogen (kg)	215	236	3.8	-	6 -
Total phosphorus (kg)	121	155	2.5	-	
pH	8.0	7.9	7.9		6.5-8.5
Sediments (ml/l)	0.1	0.1	0.1	ml/l	0.5 ml/l [u]
Heavy metals [v] (kg)	3.5	2.4			
of which: zinc (kg)	3.2	2.2	35	µg/l	1,000 µg/l
Tritium with distilled active sewage (GBq)	30,100 [q]	780	780	GBq	37,000 GBq [w]
Tritium in secondary cooling water from DR3 (GBq)	77	182	2.0	kBq/ml	370 Bq/ml
Unspecified ß activity in treated sewage [x] (GBq)	0.055	0.154	0.0025	Bq/ml	0.15 Bq/ml
Sewage sludge					
Sewage sludge (tonnes)	11	4			
Heavy metals [y] (g)	17,500	4,700			
of which: Mercury (g)	57	21	5	mg/kg	0.8 mg/kg [z]
Cadmium (g)	57	13	3	-	0.8 -
Nickel (g)	285	94	22	-	30 -
Lead (g)	422	106	25	-	120 -
Copper (g)	3,110	1,130	266	-	1,000 -
Zinc (g)	7,830	1,680	395	-	4,000 -
Uranium (g)	57	21	5		*2-10* -
Waste					
Waste to be disposed of outside Risø (tonnes)	133	145			
of which: Municipal refuse (tonnes)	77	64			
Mixed waste (tonnes)	50	74			
Chemical waste (tonnes)	6	7			
Waste for recycling (tonnes)	78	85			
of which: Waste paper and pulp (tonnes)	31	37			
Waste metal (tonnes)	45	41			
Waste for disposal at Risø (tonnes)	9	8			
Low-level radioactive waste from Risø [aa] (tonnes)	6	4			
Low-level radioactive waste from elsewhere [aa] (tonnes)	2	2			

Notes to Risø's Green Account

a Whenever Risø's endorsements specify limit values, these are noted. In some fields there are no limit values. As a comparison, as far as possible, limit values characteristic of equivalent areas/fields have been given in italics.

b Absences due to illness includes absences for appointments with doctor or dental and for occupational injuries, but excludes the first day off because of a sick child.

c The average number of days lost due to sickness for selected sector research institutions including KVL in 1999.

d The number of injuries, as in previous years, is calculated as all injuries treated by Risø's emergency room, i.e. it includes DMU, visitors and external tradesmen in addition to Risø's own employees.

e Per 1,000 man years.

f Per 1,000 employees in research and development in the areas of natural science and technology. For teaching and research as a whole: 10 accidents/1,000 employees. Source: Reported industrial accidents, annual report 1996: National Institute of Occupational Health report no. 2.

g The number of cases reported by Risø, i.e. cases reported by other parties (e.g. general practitioners/hospitals) are not included.

h Maximum individual effective dose: the individual effective dose is defined as the sum of the equivalent doses to each separate organ multiplied by its respective tissue weight factor. The maximum individual effective dose corresponds to the maximum dose to an individual employee.

i Radiation protection: Dose-limitation principles are applied in the areas of radiation protection. These state that doses from exposure to radiation at work should be kept as low as reasonably achievable and that doses must not exceed the dose limits set by the government authorities.

j The collective dose to Risø's employees is defined as the sum of the individual doses received by all persons (effective doses).

k Roskilde Municipality's sewage plan, 1988.

l DR 3 and RERAF are not included in the electricity consumption figures by area, as this consumption is unique to Risø.

m Average electricity consumption by area for education and research. For offices and industry, electricity consumption is 51 kWh/m2 (The Danish Energy Agency, 1999).

n Average heating consumption by area for education and research. For offices and industry, heating consumption is 113 kWh/m2 (The Danish Energy Agency, 1999).

o Most of the natural gas was used to produce heat and electricity for Risø, DMU and the other institutions on Risø's grounds.

p Account of consumption of fully and partially halogenised hydrocarbons used for cooling purposes.

q Exceptionally large due to a leak in DR 3.

r The dose from tritium, argon and iodine emissions are effective doses received by an imaginary person standing at Risø's perimeter fence in the same place all year round.

s The maximum contribution from companies such as Risø is suggested by various national government authorities and international organisations as being between 100 and 300 mSv/year.

t The limit value is estimated from the amount of sewage discharge permitted per 24 hours under dry weather conditions.

u Guidelines for the amount of sediment after standing for two hours.

v The total content of the heavy metals for which Risø analyses its sewage. Analysis is performed for lead, cadmium, copper, zinc and uranium. (Heavy metals: metals with a specific gravity in excess of 5 g/cm3).

w Average emissions over the last 5 years multiplied by 10, but excluding the abnormally high emissions in 1999. Risø has to report to the government authorities if annual emissions are equal to or greater than 10 times average emissions.

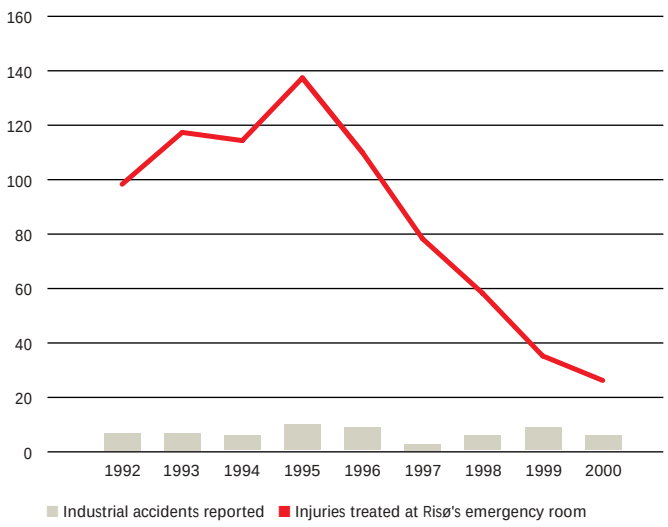
x Unspecified b activity: total activity of unspecified isotopes.

y The total content of heavy metals for which Risø analyses its sludge. Analysis is performed for arsenic, lead cadmium, chromium, cobalt, copper, mercury, lanthanum, manganese, nickel, praseodymium, zinc thorium and uranium.

z The limit values for the heavy metal content of sludge apply if the sludge is to be spread on land to be used for agricultural purposes. Risø's sludge is not currently used for this purpose, but is disposed of at Risø's controlled disposal site. The limit value for cadmium was changed to 0.4 mg/kg with effect from 1 July 2000.

aa Low-activity waste deposited temporarily at Risø derives from Risø's own activities as well as including waste radioactive material from the rest of Denmark which Risø is obliged to receive. Low-activity waste is radioactive waste for which the dose rate at distance of 1 m from the surface of the waste container does not exceed 5 mSv/h.

Industrial accidents
Injuries treated at Risø's emergency room and industrial accidents reported to the Labour Inspection Service



The Green Account shows Risø's key environmental figures for 1999 and 2000. Statutory values or typical reference values are included for comparison purposes.

The figures for 2000 are generally better than those for 1999, with the exception of tritium emissions and fire alerts.

Risø's airborne tritium emissions were higher than normal in 1999 as well as in 2000, though in neither year did the emissions exceed statutory levels. The background to this is that corrosion detected in the DR3 research nuclear reactor indicated that the unit was approaching the end of its economic life. The DR3 reactor was accordingly shut down permanently in 2000.

The greater number of fire alarms in 2000 was mainly due to the larger number of conversion projects in 2000 compared to 1999. The two fires/suspected fires in 2000 did not cause serious damage or financial loss.

Risø's safety management project has already brought about changes covering safety policy, safety organisation and nuclear safety organisation. In 2000, the safety management project came to an end following changes to Risø's emergency organisation.

These changes include the setting up of local emergency response units, and safety plans for all departments. Risø's own fire service was discontinued, and all employees took a refresher course in basic fire fighting. Fire safety at Risø's nuclear plant was improved, including new fire alarm systems linked directly to the Roskilde Fire Service. During 2001, procedures will be changed so that the Roskilde firefighters are not alerted unnecessarily.

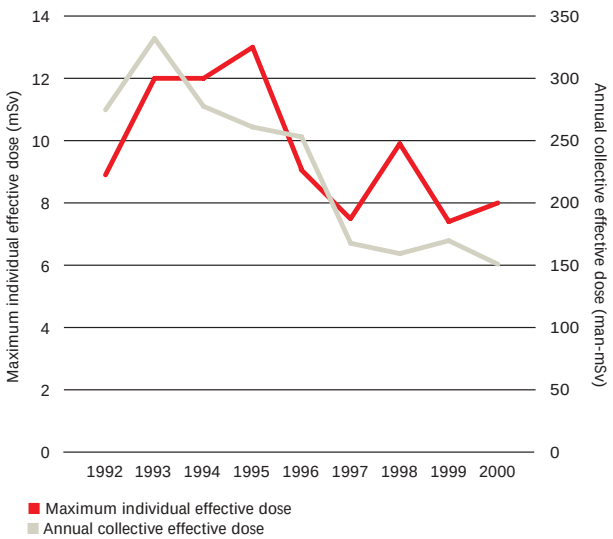
Response to Risø's new safety organisation was positive, and there was general agreement that the systematic involvement of management at all levels of the safety organisation had improved safety at Risø.

The number of injuries treated in Risø's emergency room has fallen significantly since 1995, but the same is not true of the number of accidents reported to the Labour Inspection Service. Accordingly, during 2000 a study of reportable accidents over the last five years was carried out. In 2001 Risø will use the results of the study to guide a specific effort to reduce the number of industrial accidents. Alongside this will run extra training in manual handling for groups of employees who have been identified as at risk.

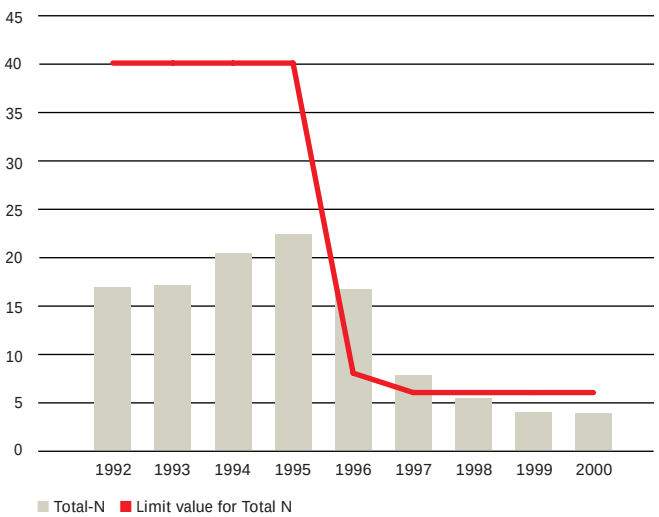
In 1996 the wastewater treatment plant was uprated to remove nitrogen. Since 1998, following a running-in period, Risø has been able to meet new emissions requirements for nitrogen of 6 mg/litre.

As the Danish authorities begin to focus more closely on corporate waste management, Risø has chosen in to include a breakdown of specific types of waste in the Green Accounts for 1999 and 2000.

Individual and collective dose
Maximum individual effective dose and annual collective dose for Risø employees as a whole



Total-N
Average concentration of total nitrogen in sewage, and the statustory limit (mg N/l)



The new Risø

In November 2000, Risø's Board of Governors adopted a Strategy for the New Risø. In its decision, the Board declared that Risø's role as a national laboratory is to promote research-based technological development which serves to create prosperity while being environmentally responsible.

Mission
To promote environmentally-responsible technological development that creates value in the areas of energy, industrial technology and bioproduction through research, innovation and consultancy.

Vision
To stimulate international development through research that forms the basis for new products and consultancy to benefit the environment, health and general prosperity. Initiatives are to be directed at areas in which research meets needs and creates new scope for industry as well as for the rest of society.

Results
To deliver new knowledge, new technologies, innovative product development and research-based consultancy.

We hope this Annual Report demonstrates that Risø lives up to the goals and frameworks that guide our work.

Risø's activities in 2000 are reported in the following publications: Risø Annual Report (available in Danish and English), Risø Annual Performance Report (Danish), and the annual progress reports of the seven research departments (English). All of these publications, and more information, are available from Risø's website at www.risoe.dk. Printed publications are available on request from the Information Service Department, telephone +45 4677 4004, e-mail risoe@risoe.dk, fax +45 4677 4013.

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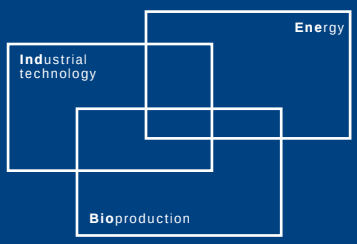
Energy
Industrial technology
Bioproduction